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A STUDY OF THE WAVE CLIMATOLOGY OF THE GULF OF SIAM

VINCENT W. ROPER

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OF THE GULF OF SIAM

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Vincent A. Roper

1960

UNITED STATES NAVAL POST GRADUATE SCHOOL

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Vincent W. Roper

A STUDY OF THE WAVE CLIMATOLOGY OF THE GULF OF SIAM

by

Vincent W. Roper
Lieutenant, junior grade
United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
METEOROLOGY

United States Naval Postgraduate School
Monterey, California

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ABSTRACT

This study deals with the wind and wave regimes in the Gulf of Siam and with their seasonal changes. Winds over the Gulf in the years 1950 through 1957 were first examined in order to select three years in which waves were to be hindcast. Then wind waves were hindcast for four geographical locations in the Gulf for the years 1955, 1956 and 1957. The statistical results are presented for each month and for each location in the form of wind and wave roses, and wave-height and wave-period diagrams.

The author wishes to express his appreciation for the advice and encouragement of Professor W. C. Thompson of the U. S. Naval Postgraduate School, under whose direction this study was accomplished. The subject was suggested to the writer by Professor Thompson following the latter's introduction to some of the navigation problems in the Gulf of Thailand by weather personnel of the Thai Naval Service in Bangkok in 1957.

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1. Introduction

Climatological wave data have proven useful in both military and civilian operations. Furthermore, the surface has just been scratched in the exploitation of its uses.

Some Naval uses are [7]: selection of landing beaches for amphibious operations; selection of optimum sites for flight and fueling operations at sea; and site studies for "Texas Towers". The Beach Erosion Board (U. S. Army, Corps of Engineers) uses wave data for planning coast and harbor structures, evaluating the failure of these structures, and for predicting natural coastline changes. The oil industry, in connection with the development of offshore oil resources, uses wave data in designing offshore oil drilling platforms and submarine pipe lines.

In many areas of the world, such as Southeast Asia, a lack of wave records and adequate visual observations precludes the assembling of statistical wave data. However, wave hindcasting, a process in which wave data are obtained from historical weather maps by the use of wave prediction techniques, can provide a simple and useful solution to the problem. Also, the necessary data can be compiled in a fraction of the time and cost of the previously mentioned methods.

The objective of this study was to compute climatological wave data for several selected locations in the Gulf of Siam by hindcasting waves using selected years of wind data.

The following discussion is divided into these phases:

a. Analysis and discussion of the wind circulation in the Gulf of Siam.

b. A statement of the conventions adopted and the assumptions made for this study.

c. A discussion of wave-generation processes.

d. A description of the hindcasting technique.

e. A description of the method used herein in selecting the years for which to hindcast the waves.

f. Statistical results obtained from the study.

2. Wind Circulation in and around the Gulf of Siam.

The objectives of this section are to discuss the location, surrounding topography, and wind circulation in the Gulf of Siam.

2A. Location and Topography.

The area of interest is located in the tropics between 5° and 15° North Latitude and between 98° and 109° East Longitude. Figure 1 illustrates the geographical location.

The Gulf of Siam is a relatively shallow body of water, the greatest depth of which is 40 fathoms[13]. Its largest dimensions are about 420 miles from north to south and 380 miles from east to west. It is bounded on the north and west by Thailand; on the northeast by Thailand, Cambodia, and Vietnam; and on the south by Thailand and the Federation of Malaya. The southeastern portion of the Gulf is open to the South China Sea.

Figure 1 also illustrates the topography surrounding the Gulf. In Thailand, the central portion of the country is a large alluvial plain flanked by mountains that extend southward along both sides of the Gulf of Siam with elevations up to 5,000 ft. The Cordillera of Annam, with heights up to 6,000 ft., stretches down the East coast of Vietnam[10].

Since most of the mountain ranges extend in a north-

south direction, they lie in the path of the prevailing Monsoon winds and cause large local differences in climate and weather.

2B. Wind Circulation.

The wind circulation of Southeast Asia is dominated by the Monsoons. They may be defined [4] as a regional circulation superimposed upon the general circulation, caused by the seasonal thermal differences between land and ocean.

In winter, when the land is cool and the ocean relatively warm; the Winter or Northeast Monsoon prevails over the Gulf of Siam from November to March, as an outflow of the intense Siberian high pressure field [11]. Figure 2 shows the mean isobars and prevailing winds at the surface for January. Note the topographic influence on the wind in and around the Gulf of Siam.

The Summer or Southwest Monsoon controls the circulation from June until August, when the continent is warmer than the adjacent ocean. A significant feature in the pressure distribution is a semi-permanent low pressure center over the northern Bay of Bengal which is related to the southwesterly flow of air over the Gulf. Figure 3 pictures the mean isobars and prevailing winds at the surface for July. Note the continuity in direction of flow over the Gulf of Siam.

Transition periods between the Monsoons are September-

October, during which the air flow shifts from southwest to northeast, and April-May, when the flow reverses from northeast to southwest. These periods are for the central latitude (about 9° North) through the Gulf, and differ somewhat at other latitudes.

The most noticeable feature of the wind velocity at a particular station in the Gulf of Siam is its persistence. Once the seasonal Monsoon is established, the wind blows from about the same direction with little change in speed for months at a time. However, it is of interest that in the northern Gulf the change in wind direction at a particular station during the shift of the Monsoons can be extremely rapid. These rapid changes are usually associated with the passage of a trough at the 500 mb level.

The mean length of the period of transition, based on data from this study for all stations in the Gulf, is 15 days. Two examples of rapid seasonal wind change are illustrated in the following table:

TABLE I
Examples of Rapid Shift of the Monsoons

Station	Dates	Wind	Station	Dates	Wind
Bangkok	Sept.-Oct.1956		Prachuap Khirkhan	Jan. 1955	
	25	S/10		21	N/10
	26	S/5		22	NE/5
	27	SW/10		23	N/5
	- - - - - - - -			- - - - - - -	
	28	E/5		24	NW/2
	29	N/5		25	W/2
	30	N/5		- - - - - - -	
	1	E/2		26	SW/2
	2	NE/15		27	SW/2
				28	SW/2

3. Conventions Adopted and Assumptions Made for this Study.

The purpose of this section is to set forth the conventions adopted and assumptions made for this study.

Wind-generated waves in the ocean can be divided into two classes: (1) sea and (2) swell. Sea, often referred to as wind waves, may be defined as waves generated by the local wind. Swell may be defined as wind-generated waves which have advanced into regions of weaker winds or calm. This paper is concerned only with wind waves since the determination of swell at the selected locations in the Gulf of Siam is beyond the scope of this study. Furthermore, since the Gulf is open only in the southeast to the South China Sea, there is little opportunity for swell to enter the Gulf. Therefore, the occurrence of swell as compared to wind waves is relatively unimportant in the Gulf of Siam and can be disregarded.

The wind waves will be described in terms of the two physical characteristics: height and period. In this study, wave height will be expressed as the "significant" wave height. This is defined as the average height of the highest one-third of all waves passing a fixed point during a given observation period (one-half hour or longer)[15]. The significant wave height was chosen because it is the standard height parameter in most wave studies and it emphasizes the larger waves present. In addition, it has been noted that a casual observer tends to report waves which lie closer to the significant wave

height than to the mean[15].

If the significant wave height (H_F) is known, other measures of wave height can be computed from Table 2[15]. The values in this table were obtained from the analysis of swell records, but they also provide a good approximation of wind waves. In the table, the figure for "relative height" is a ratio of any particular height, such as average height, to the significant height.

TABLE 2
Comparison of Wave Height Parameters

Wave Height	Relative Height
Significant	1.00
Average	0.64
Highest Ten Percent	1.29
Highest Wave	1.87

In this study, the period of the wind waves will be expressed as "significant" period (T_F). This is defined as the average period of the highest one-third of the waves passing a fixed point during a stated interval of time (one-half hour or longer).

Only waves of two feet or more in height and four seconds or greater in period were regarded as being worthy of note.

An important assumption made in this study is that the forecasted wind waves occur in deep water. Accordingly, no modifications were made for shoaling or refraction of the waves in shoal water.[1] Deep water is defined as

[1]To apply a shoaling correction, the spectral periods, as described in H.O. 603[18], should be used. Since only T_F is determined in this study the shoaling correction would be an approximation.

$d/L_o \geq 1/2$, where d = water depth and L_o = deep-water length [15]. Since the Gulf of Siam is relatively shallow, as mentioned in Section 2, all waves of period 9.7 seconds or greater in depths of 40 fathoms and 6.8 seconds or greater in depths of 20 fathoms should be modified by applying the proper shallow water relationships (H.O. 234) [14] to obtain more accurate wave heights and periods. However, for the relatively short periods of waves that this study shows to prevail in the Gulf, this assumption is valid for all portions of the Gulf that are normally navigable by coastal steamers.

Another assumption made is that the wind recorded at a station, for example Prachuap Khirkhan, has blown across the entire fetch with the same direction and speed. In the case of wave-forecasting stations Three and Four, (see Figure 5) for which no wind records are available, "mental streamlines" were drawn through the winds reported at adjacent stations, and the wind speed and direction values at these stations were interpolated.

4. Generation and Growth of Wind Waves.

The discussion in this section is given to describe briefly the basic theories of wind-wave formation and growth.

When a light wind "springs up" over a calm body of water, tiny wavelets are observed which form in more or less regular arcs of long radius. These are termed "capillary waves" since their dimensions and speed are determined by the surface tension of the water[21]. Both the period and wave length are extremely short, being on the order of a fraction of a second and an inch, respectively.

When the wind speed increases to approximately 2.2 knots, larger additional waves are generated, dominantly under the restoring force of gravity[17], and are called "gravity waves".

Waves grow in size by the transfer of energy from the wind to the waves through the push of the wind against the wave crests (normal pressure) and pull of the wind on the water particles (tangential drag)[15]. While the wind is blowing, a state of irregular composite wave motion, called "sea", occurs in which the total wave energy is spread out over a range of periods and directions (centered about the mean wind direction)[18].

The height of the waves present in the area of wave formation at a particular time depends upon:

a. the wind speed

b. the fetch (the stretch of water over which the wind has blown)

c. the duration of the wind (the length of time the wind has blown)

d. the depth of the water, if shoal water (assumed deep in this study)

e. the waves which were present when the wind started blowing.

In the Gulf of Siam, the height of the waves for a given wind speed depends primarily upon the fetch and the duration. In this study it was found that the duration of the wind was the governing factor during periods when moderate to high winds were interspersed with days of calm winds, since the wind speed changes limited the growth of the waves. On the other hand, when the wind speeds underwent little change from day to day, the fetch at a particular station became the limiting factor.

A fully developed state of the sea occurs when a given wind has blown for a sufficiently long duration over a sufficiently long fetch. In this state, the rate of energy input by normal and tangential stresses is just equalled by the rate of wave energy dissipation, principally by white-cap formation 18 .

Fully developed states of the sea occur in the Gulf of Siam primarily for wind speeds of less than 15 knots. It can be seen in Figure 4 that a 15 knot wind requires a fetch of 300 nautical miles and a wind duration of 30 hours to produce a fully developed sea state. For winds greater

than 15 knots blowing for 30 hours or longer, the fetch becomes a limiting factor because there are few stations with fetches in the Gulf greater than 300 nautical miles except in the southeast direction. Table 3 below gives the fetch lengths (in nautical miles) at the four wave hindcasting stations for which waves were forecast in this study.

TABLE 3*

Limiting Fetches at the Four Wave Hindcasting Stations

Direction	Station 1	Station 2	Station 3	Station 4
N	---	375	110	195
NE	75	270	25	110
E	150	915	760	140
SE	855	---	570	580
S	150	---	420	180
SW	---	---	190	155
W	---	---	270	155
NW	---	---	370	240

* All distances in nautical miles.

5. Technique of Obtaining Statistical Wave Information.

In this section, some background is given on the hindcasting technique, including its inherent advantages and disadvantages. Reasons are given for use of the wave forecast graphs employed in this study.

5A. The Wave Hindcasting Technique.

"Necessity is the mother of invention", is a rather trite metaphor. Nevertheless, it can be said that World War II gave birth to the greatest period of progress in the theory, observation and prediction of sea, swell, and surf.

As early as 1942, W. H. Munk[3] in the Oceanographic Section, Directorate of Weather, Army Air Force, was assigned the task of developing a wave forecasting method to be used in the invasion of North Africa. During early 1943 Munk and H. U. Sverdrup, Director of Scripps Institution of Oceanography, devised a technique which combined both observed data and the classical equations of hydrodynamics to explain the processes of wave generation and decay. The results were later published in the form of forecasting graphs[20]. These were subsequently revised by R. S. Arthur in 1947[2], and later, on the basis of additional observed data, by C. L. Bretschneider in 1952[6]. The wave forecasting method is now referred to as the Sverdrup-Munk-Bretschneider method or the SMB method.

In 1954, W. J. Pierson Jr., G. Neumann and R. W. James of New York University devised a method of fore-

casting ocean waves based on wave spectra and statistics [18]. The PNJ or Wave Spectrum Method, as it is termed, describes the sea surface as the result of the combination of an infinite number of low-amplitude sine waves varying in frequency and direction.

A comparison of the SMB and PNJ methods is given in the foreward of H.O. Pub. No. 603 [18] which states:

> The Pierson-Neumann-James and Sverdrup-Munk(-Bretschneider) theories for forecasting sea conditions are similar in that the basic equations were deduced by analyzing a great number of observations by graphical methods using known parameters of wave characteristics. On the other hand, the two theories are dissimilar when dealing with swell. The former technique relies strictly on the theoretical considerations of angular spreading and dispersion of the various components of the spectrum, whereas the latter technique is partly theoretical and partly empirical.

5B. Reasons for Using the SMB Wave Forecasting Curves.

Since this paper is concerned with obtaining data for only the significant wave height and period, the author felt that the SMB curves were more convenient to use. The wave height and period can be read directly off the SMB graph (see Figure 4) by entering with the pertinent wind velocity, fetch, and duration. The graph also contains lines of "equal energy" which allow rapid computation of waves being produced during periods of varying wind speed by the method described by Bretschneider [6]. For example, 20 knots of wind blowing for 12 hours generates waves with the same energy of those produced by a 30 knot wind blowing for four hours.

Both methods can be used to arrive at various

descriptions of the wave height, such as "most frequent", "average", "significant" and "average of the 1/10 highest" waves, and both give nearly identical results in the forecasting of wave height produced by wind waves. Furthermore, as mentioned in Section 3, there are essentially no swell of importance in the Gulf of Siam. The forecasting of wave period by the PNJ method is most time consuming but yields more information in the form of the range of significant periods present and the period of maximum energy concentration. The SMB method yields only the significant period (T_F), which is essentially equivalent to the period of maximum energy concentration of the PNJ method.

The following is a short example in the use of Figure 4. Given: wind speed (U) 22 knots; fetch (F) 400 nautical miles; duration (t_d) 18 hours. From the graph: significant wave height (H_F) 10.0 ft.; significant wave period (T_F) 8.3 seconds.

5C. Advantages and Disadvantages of the Hindcasting Method.

The advantages and disadvantages of the wave hindcasting method for obtaining statistical wave data are as follows [22] [9]:

Advantages:

a. Wave data can be inferred for any location in the oceans and for any interval in the past if adequate weather maps are available; whereas, there are very few regions where adequate records of actual waves are available.

b. Wave data can be provided in a short period of time.

Burt and Saur[7] state that, "two forecasters and three statistical clerks can compute, in about four months the deep water wave characteristics over a three year period for the California coast". Other methods necessarily require continuous observations during the entire year.

c. Hindcasting is not hampered by gaps in the wave record caused by instrument failure or by inability to obtain visual observations.

d. Variability of the mean wave action from year to year can be estimated readily by hindcasting waves over a selected number of years.

e. Cost of hindcasting is very low compared to the cost of installing and maintaining wave recorders, and analyzing the results from wave records or visual observations.

f. Wave data compiled from visual observations or wave records are generally collected from specific shallow-water locations, and the data cannot readily be applied to adjacent areas; whereas, wave data are hindcasted for a given location in deep water, and appropriate corrections can be applied[14] to obtain the wave data in adjacent shallow water areas.

Disadvantages of the technique are:

a. The wave forecasting technique has not been fully tested by comparing forecasted waves with observed waves because of the lack of adequate observations; however, the few comparisons that have been made indicate that the hindcasting technique yields quite satisfactory results for climatological purposes.

b. Wave hindcasts are subject to errors in judgment and to arithmetical errors, but these tend to compensate or to disappear in the statistical treatment.

c. Wave forecasts differ between forecasters because the estimation of wind speeds over water areas from weather maps is somewhat subjective.

5D. Procedure for Applying the Hindcasting Technique:

The procedure used by the writer for compiling climatological wave data by application of the hindcasting technique was as follows[22].

First, weather maps were chosen that cover the entire ocean area from which waves can be generated and influence the forecast location. This area includes the Gulf of Siam and the adjacent South China Sea. The maps that were selected were the Daily Series of Synoptic Weather Maps of the Northern Hemisphere[8] for the years 1955, 1956, and 1957. The reason for the selection of these years is discussed in Section 6. These maps are for 24 hour intervals and utilized the 1200Z reports. Intervals of 12 hours are preferable, especially in mid-latitudes, but 24 hourly maps can be used in an area such as the Gulf of Siam due to the persistence of the winds. For days when data were missing, estimates of wind speed were made from preceding and succeeding days, and wind reports from nearby secondary stations were also utilized. If a particular station had more than 30% of its reports missing during a month, the data for that month were dropped (e.g., Songkhla in August, September, and October 1957). Part II of the Daily Series of Synoptic Weather Maps of the Northern Hemisphere[8] was particularly useful in furnishing wind data for secondary stations.

It is to be noted that since all reporting stations in the Gulf were below 20° North Latitude, only observed winds at the stations were used. No attempt was made to obtain wind speeds from the pressure gradient due to its gross inaccuracy at these low latitudes.

Second, the SMB wave forecasting technique was applied to the weather maps in order to obtain the wind

waves for four selected sites in the Gulf of Siam. The location of these stations can be seen in Figure 5. The reasons for the selection of these particular sites is discussed in Section 6. Only wind waves were forecast and no shallow water corrections were made.

Finally, a climatological compilation of the deep-water wave data was made by tabulating the number of hours for each month that waves of different heights and periods arrived at the stations from various possible directions. These data, in the form of wave roses and wave-height and wave-period diagrams, can be seen in the appendices of this paper.

6. Selection of Representative Years of Wind Data and Sites for Forecasting Wind Waves.

The objective here is to explain why 1955, 1956, and 1957 were chosen as the years for which wind data were used for forecasting waves. The reasons are also given for selecting the sites of the four wave forecast locations.

6A. Selection of the Years.

Because it is important in such a study as this to use representative years of wind-speed data, a scientific method was used for their selection as follows:

First, a group of years contained in one sunspot cycle (about 11 years) was selected (1947 through 1957). Regarding the use of one sunspot cycle, Stetson [18] felt that during this eleven-year period, an extreme range of climatic variations over the earth will occur. Unfortunately, eleven years of wind data from a sufficient number of observing stations were not available. Prior to 1950, there were two reliable stations around the Gulf in operation, namely Bangkok, Thailand and Kota Bhaur, Federation of Malaya, which had been taking observations as early as 1936 [12]. However, in 1950 there were seven stations ringing the Gulf which were reporting on a regular and reliable basis. Therefore, the years 1950 through 1957 were sampled.

Second, a random choice of three dates was made from one month (11th, 21st, and 27th). The wind speeds for the years 1950 through 1957 were sampled by means of the reports during these three days per month.

Third, the average monthly and yearly wind speeds were then computed and graphed (see Figure 7).

Finally, from examination of these eight years of wind data, three years were selected as follows:

a. A year of maximum wind speed: 1955

b. A year of minimum wind speed: 1957

c. A year of average wind speed: 1956

This study showed that the year-to-year variability in the wind speeds around the Gulf are small and that sampling of years from a sunspot cycle is apparently not important.

6B. Selection of the Sites.

The wind reporting stations chosen on the basis of geographical distribution and regularity of reports were; Bangkok, Prachuap Khirkhan, and Songkhla, Thailand and Conson, located on the Ile Poulo Condor off the South coast of Vietnam. Bangkok was chosen because it is the station which gives first indication of any shift of wind direction in the Northern Gulf. Prachuap Khirkhan is related to Wave Station 1 and Songkhla to Wave Station 2. The wind field between Songkhla and Conson primarily governs the waves at Stations 3 and 4.

Four wave hindcasting sites were selected in the following geographical locations so as to cover the Gulf: Station No. 1, just off Prachuap Khirkhan, Thailand (11° 48' N, 99° 48' E); Station No. 2, just off Songkhla, Thailand (07° 11' N, 100° 37' E); Station No.3, at 08° 30' N,

104° 30' E and Station No. 4 at 09° 00' N, 102° 30' E. They are shown in Figure 5 (the limiting fetches for each are given in Table 3).

Wave Stations 1 and 2 are spaced so as to give a representative picture of the wave data along the western side of the Gulf. They were placed just off of their respective cities so that the wave data would be for points beyond breaking depth most of the time. Both Prachuap Khirkhan and Songkhla are reliable synoptic reporting stations for wind direction and speed.

Station No. 3 is located about 20 miles WNW of Ile Poulo Obi. This site on the east side of the Gulf was chosen because it is a heavily trafficked area for ships entering the Gulf of Siam from the east and southeast.

A "caution" notice on H.O. Navigation Chart No. 3132 (Gulf of Siam) states that the bank in the vicinity of Pointe de Ca Mau and Ile Poulo Obi is extending seaward at a relatively rapid rate. This is due to heavy deposition of sediment from the many rivers in this southwestern portion of Vietnam. It is possible that wave data for Station No. 3, contained herein, may be useful to coastal engineers in determining the effect of the waves and longshore currents on the formation and growth of this bank.

Station No. 4 was placed in the center of the lower Gulf to complete the picture of the wave conditions in the Gulf.

The large bay just to the south of Bangkok was not chosen as a site since the waves there are relatively

small and are fetch-limited from all directions, except from the south. Station No. 1 will provide representative data for this direction.

No sites were selected on the northeastern side of the Gulf due to the dearth of reporting stations between Bangkok, Thailand and Kampot, Cambodia.

7. Results of the Study.

The objective of this section is to present the results obtained from this study on the wind and waves in the Gulf of Siam.

7A. Winds Over the Gulf.

From daily reports of wind speed and direction for four of the seven reporting stations considered in the Gulf for the years 1955, 1956, and 1957 (namely Bangkok, Prachuap Khirkhan, and Songkhla, Thailand and Conson, Vietnam), a tabulation was made of the percent frequency of occurrence of certain ranges of wind speeds for each of eight compass directions. The compilation of these data can be seen in the form of wind roses in Appendix I.

The wind roses for January indicate that the winds at Bangkok begin to shift to the SW regime. Prachuap Khirkhan, about 120 miles to the south of Bangkok, is still under NE flow as are Songkhla and Conson. By February, the shift of southerly winds reaches as far south as Prachuap Khirkhan. Note that at this station and Bangkok the winds are predominantly from the south and not the southwest. This is believed to be due to the funneling effect of the mountain range of 3,000 to 4,000 feet elevation that runs along the west coast of the Gulf. Songkhla and Conson still exhibit the characteristics of winter flow. The picture in March is essentially that of February with no major changes in wind directions taking place. In April, Songkhla and Conson both have a small

percentage of the winds from the W or SW and by May all stations in the Gulf are characterized by winds predominantly from the SW or W. The summer months of June, July, and August are quite similar and exhibit little change from the flow established in May. In September, all stations show a definite weakening of the flow from the SW and W as indicated by a small percentage of winds from the NE. The wind roses for October indicate that the shift of the winds to the NE monsoon is almost completed for the northern two stations(Bangkok and Prachuap Khirkhan) while the two southern stations are in the midst of change to the NE. November and December are the best examples of the NE monsoon over the Gulf. The wind flow over all stations is then dominantly from the directions of NE and N.

The months with the greatest number of calm days reported were April and May (28% and 34%), and September and October (30% and 37%). These two sets of months can be termed as the transition periods between the Winter and Summer Monsoons for stations in the central Gulf of Siam.

There were fewer days of calm winds reported in winter than summer. On the whole, the wind speeds were considerably higher in the winter (November through March) than in the summer (June through August). It is of interest to note that Songkhla, especially in the winter, consistently reported higher wind speeds than surrounding stations. This may be due to a topographically formed convergence zone over this location.

7B. Waves in the Gulf. (as hindcast)

Appendix II contains graphs of wave height and wave period versus the number of hours per month the height or period is less than or equal to a particular height or period. It should be noted that this is the "significant" height (H_F) and "significant" period (T_F) as explained in Section 6. Some wave heights recorded in the Gulf were much higher and some periods were much longer.

It can be readily seen that the highest waves for the sites chosen occurred in the winter months. Furthermore, the highest waves were hindcast on the western edge of the Gulf just off Songkhla (Station 2).

January and February produced, at Station 2, the highest waves recorded in the Gulf during this study. The heights were 23 and 25 feet respectively with periods of 12 seconds. The heights steadily decreased and the periods shortened through May, when Station 3 recorded a height of five feet and a period of seven seconds, the maximum values for that month. During the months of June, July, and August the values of wave height and period increased, attaining a maximum of 14 feet with nine second periods. September exhibited low wave heights and periods, the maximum being five feet and seven seconds at Station 3. The winter Monsoon brought an increase in wave height and period through the months of October, November, and December. The maximum values for this period occurred in November at Station 2. The heights were 17 feet with periods of 10 seconds.

The figures read from the graphs in Appendix II do not take wave direction into consideration. The wave roses for the selected sites give a good picture of wave heights with respect to directions (see Appendix III).

Wave Station 1 is sheltered considerably by land to its west and is affected by waves from the NE, E, SE, and S only.

Station 2 is open to wave action only from the N, NE, and E.

Stations 3 and 4, being in open water, have fetches greater than 100 nautical miles in all directions (except from the NE for Station 3, where the fetch is 25 nautical miles).

7C. Summary

The winds are strongest in the winter (NE Monsoon) season in the Gulf of Siam. Hence, these high winds frequently produce waves of appreciable height and period at the wave forecasting sites chosen. The maximum significant wave dimensions computed were a height of 25 feet and a period of 12 seconds on the west side of the Gulf.

In comparison, the summer and both transitional periods were climatologically seasons of low and relatively negligible wave heights, due to the lower wind speeds and the geographical locations of the wave hindcast sites chosen. The dimensions of the significant waves were a height of 14 feet and a period of nine seconds on the southeast side of the Gulf.

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Figure 1. Area and Topographic Map of Southeast Asia.

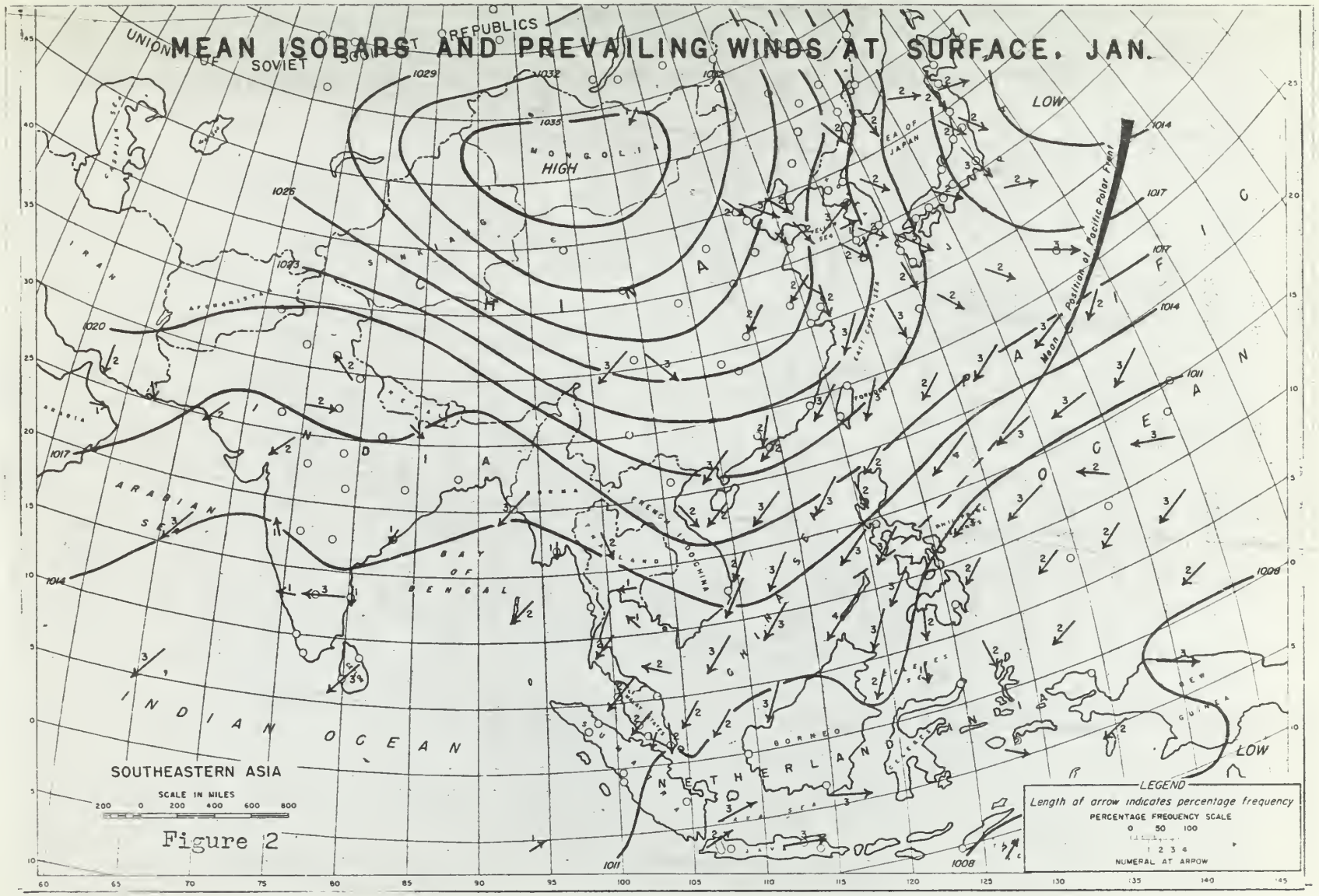

MEAN ISOBARS AND PREVAILING WINDS AT SURFACE. JAN.
UNION OF SOVIET SOCIALIST REPUBLICS
MONGOLIA
HIGH
LOW
Mean Position of Pacific Polar Front
CHINA
INDIA
IRAN
ARABIAN SEA
BAY OF BENGAL
INDIAN OCEAN
FRENCH INDOCHINA
BORNEO
NETHERLANDS
EAST CHINA SEA
SEA OF JAPAN
NEW GUINEA
1035
1032
1029
1026
1023
1020
1017
1014
1011
1008
SOUTHEASTERN ASIA
SCALE IN MILES
200 0 200 400 600 800
LEGEND
Length of arrow indicates percentage frequency
PERCENTAGE FREQUENCY SCALE
0 50 100
1 2 3 4
NUMERAL AT ARROW

Figure 2

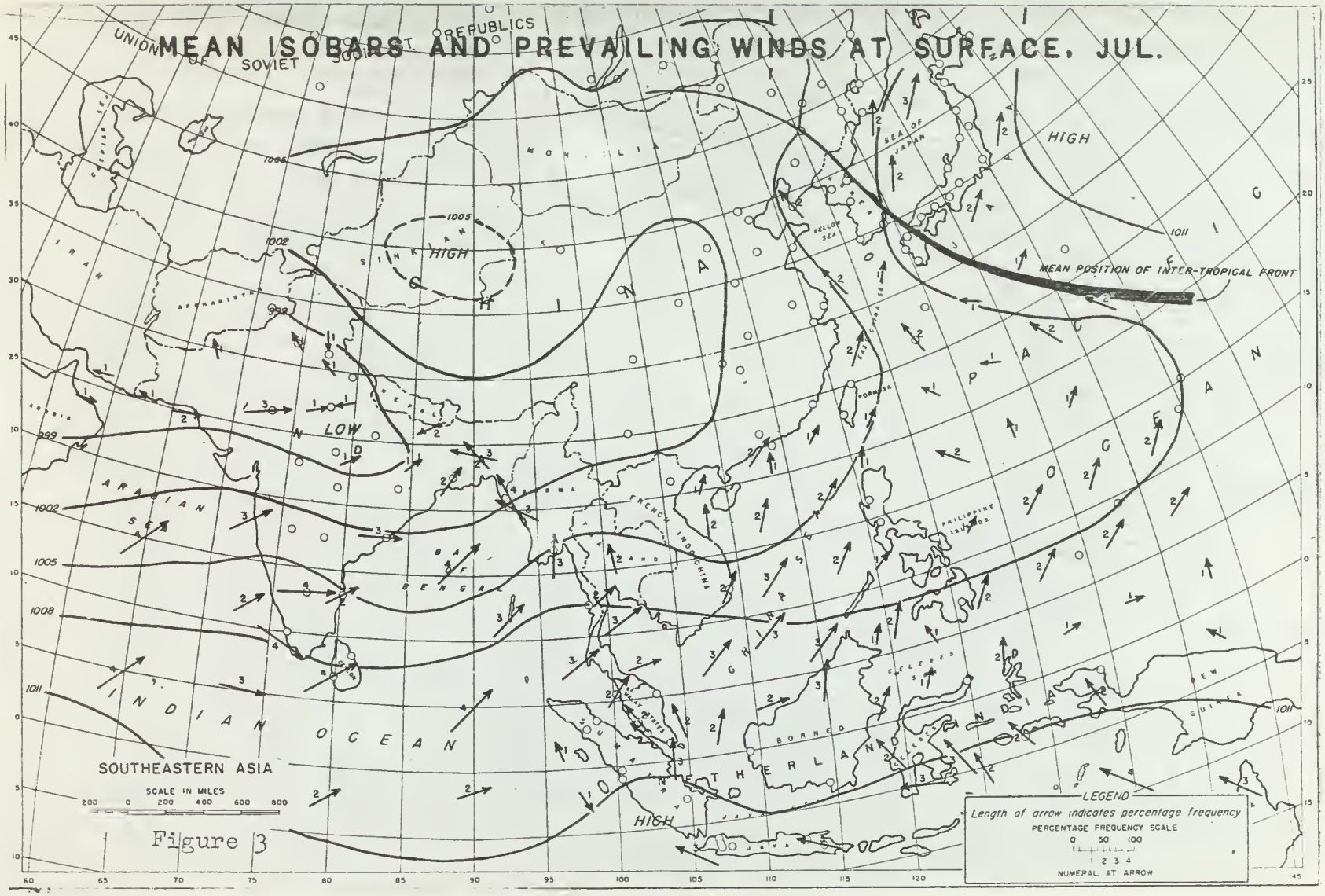

MEAN ISOBARS AND PREVAILING WINDS AT SURFACE. JUL.
UNION OF SOVIET SOCIALIST REPUBLICS
MONGOLIA
IRAN
AFGHANISTAN
ARABIA
ARABIAN SEA
BAY OF BENGAL
CEYLON
INDIAN OCEAN
SIBERIAN HIGH
LOW
HIGH
SEA OF JAPAN
YELLOW SEA
FORMOSA
FRENCH INDOCHINA
PHILIPPINE ISLANDS
BORNEO
CELEBES
NEW GUINEA
SOUTHEASTERN ASIA
SCALE IN MILES
200 0 200 400 600 800
MEAN POSITION OF INTER-TROPICAL FRONT
LEGEND
Length of arrow indicates percentage frequency
PERCENTAGE FREQUENCY SCALE
0 50 100
1 2 3 4
NUMERAL AT ARROW

Figure 3

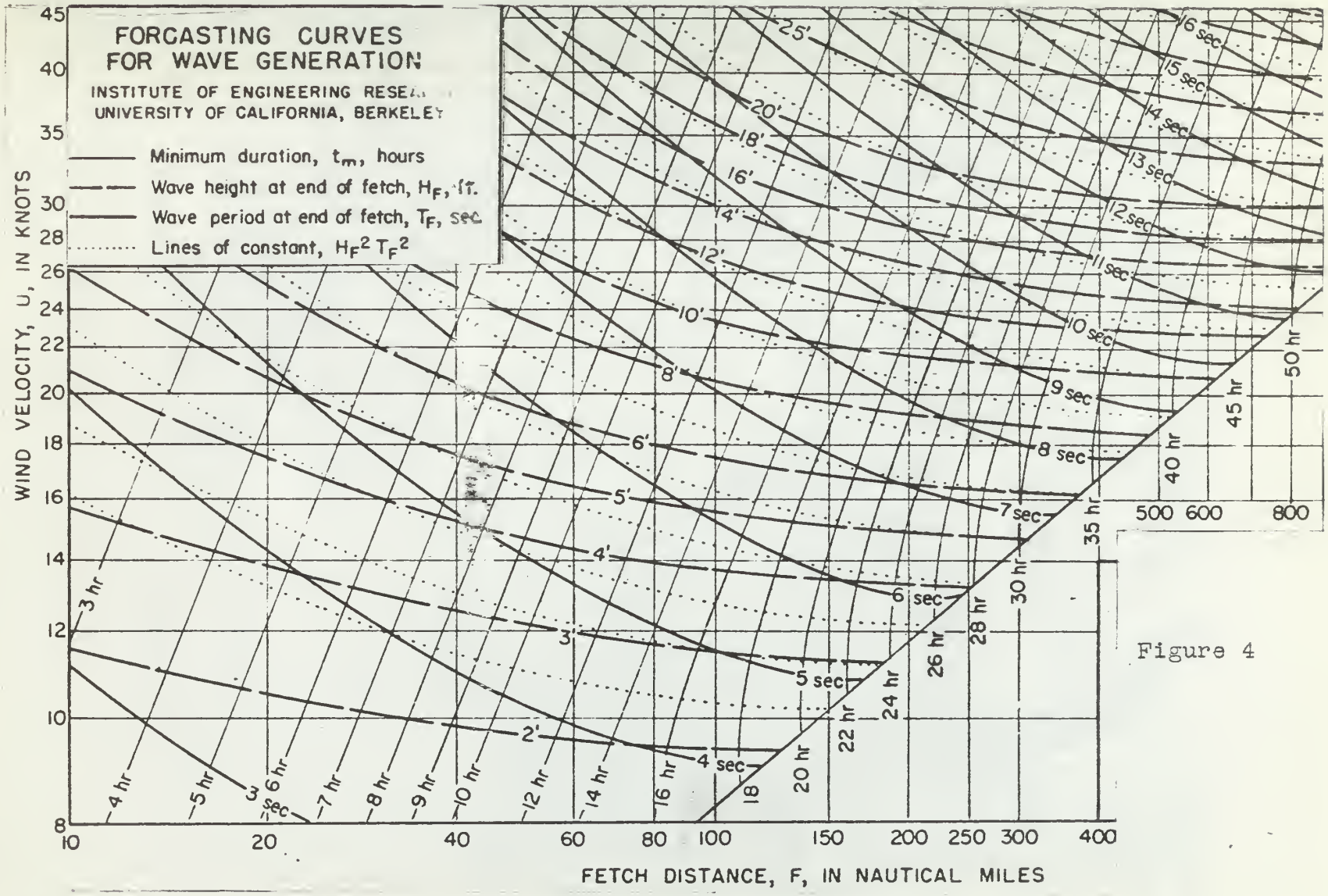

FORCASTING CURVES
FOR WAVE GENERATION
INSTITUTE OF ENGINEERING RESEA
UNIVERSITY OF CALIFORNIA, BERKELEY
Minimum duration, t_m, hours
Wave height at end of fetch, H_F, ft.
Wave period at end of fetch, T_F, sec
Lines of constant, $H_F^2 T_F^2$
WIND VELOCITY, U, IN KNOTS
FETCH DISTANCE, F, IN NAUTICAL MILES

Figure 4

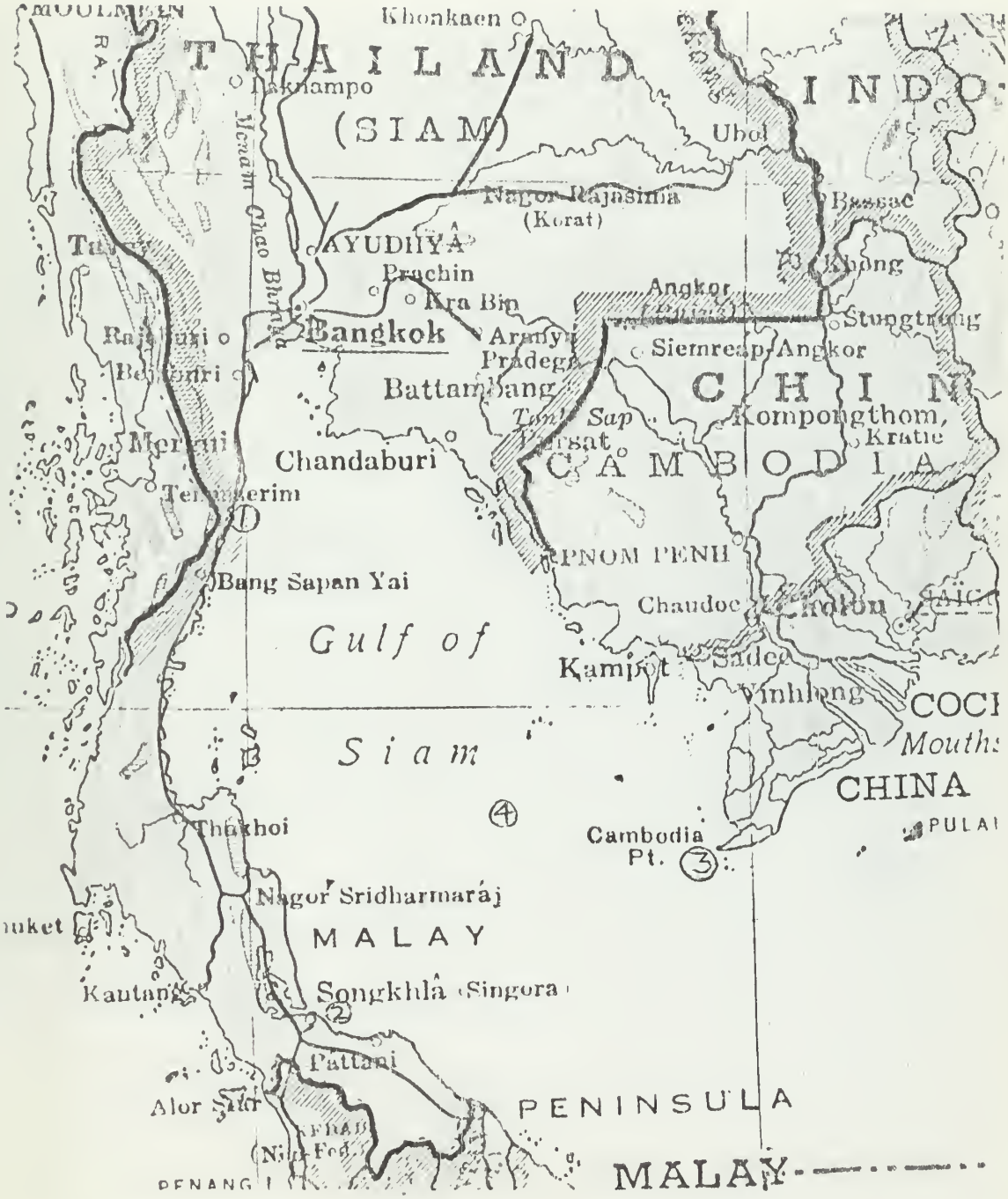


Figure 5. Four Sites in the Gulf of Siam for which Waves were Hindcast.

Figure 6. Seven Wind Reporting Stations in the Gulf of Siam.

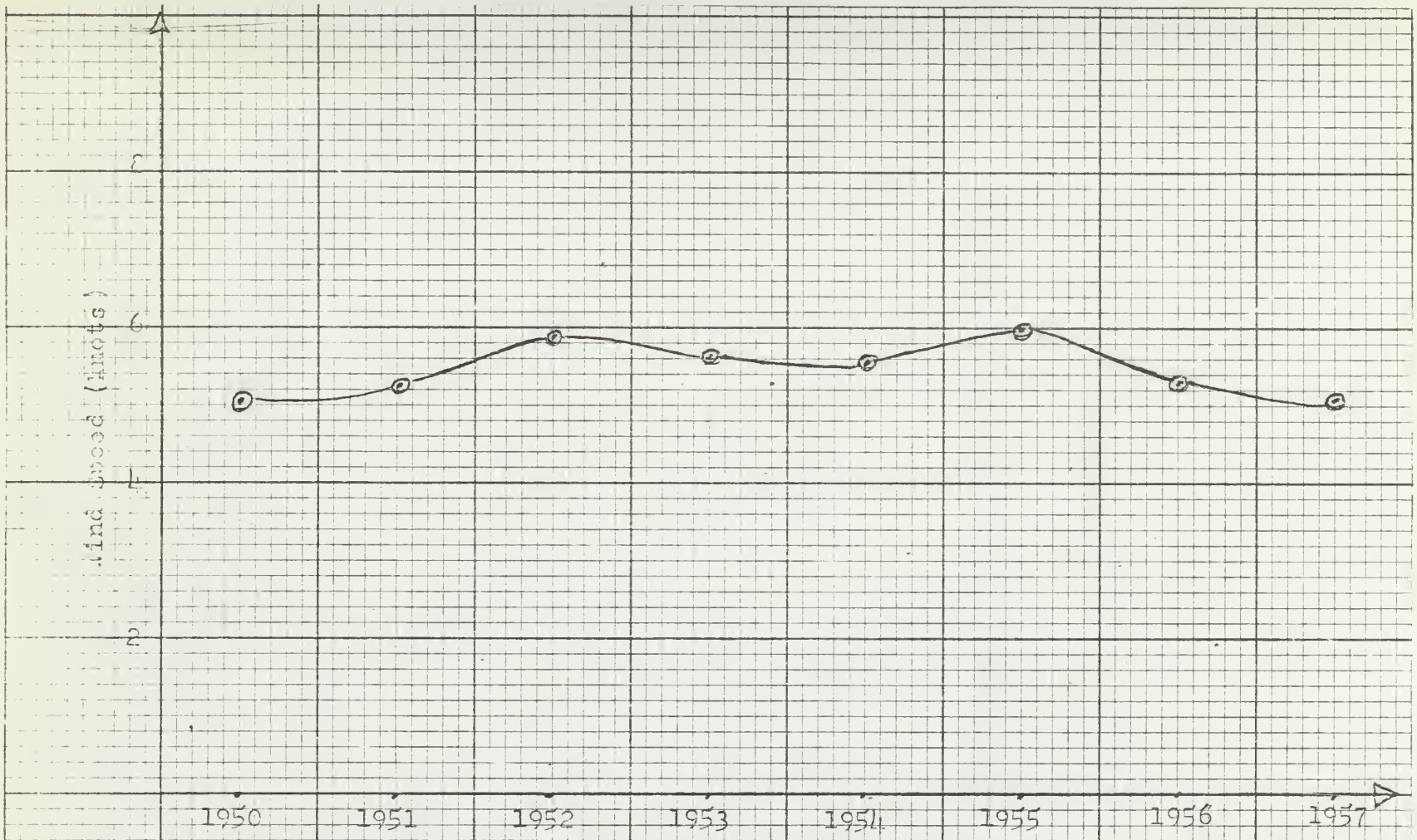
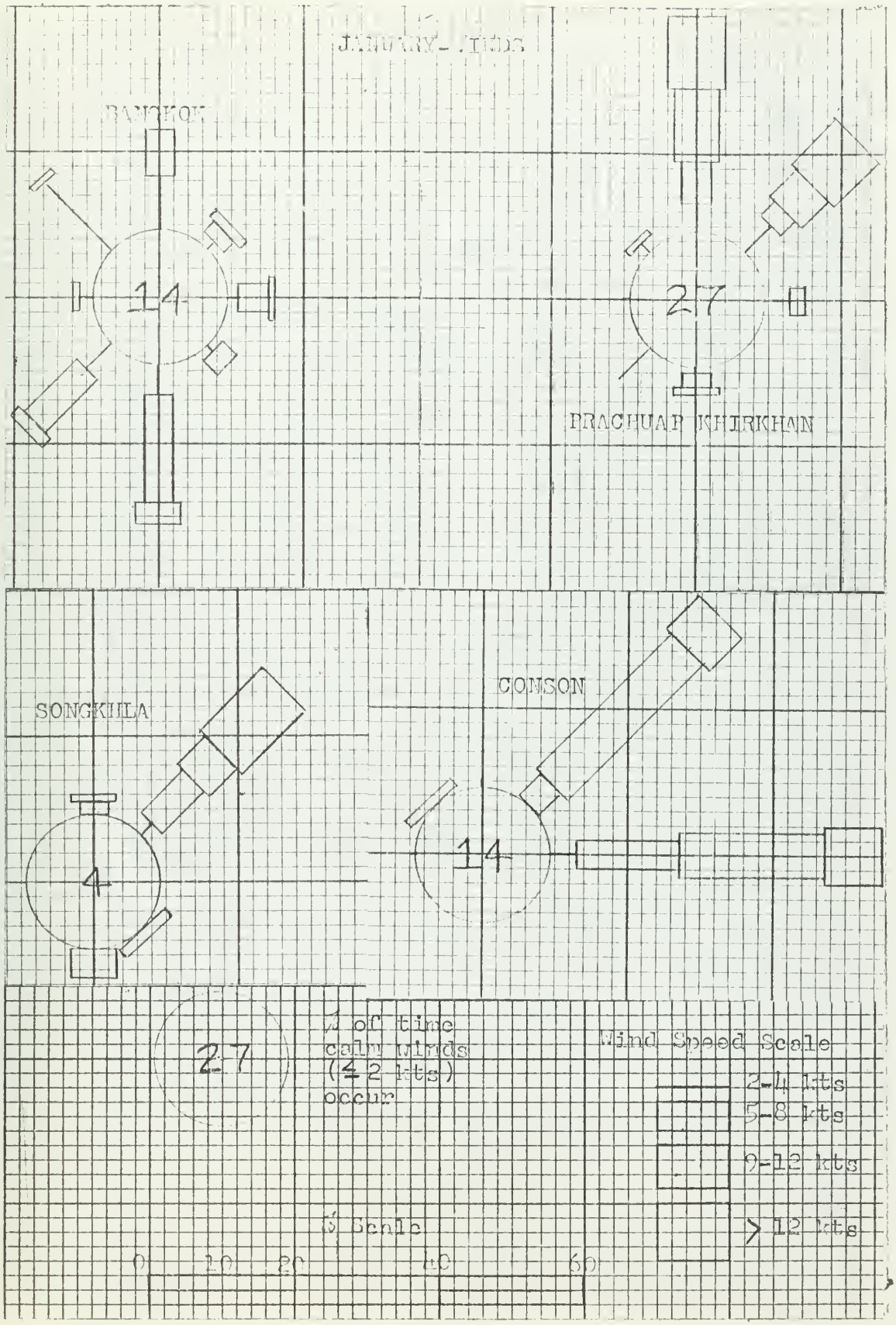
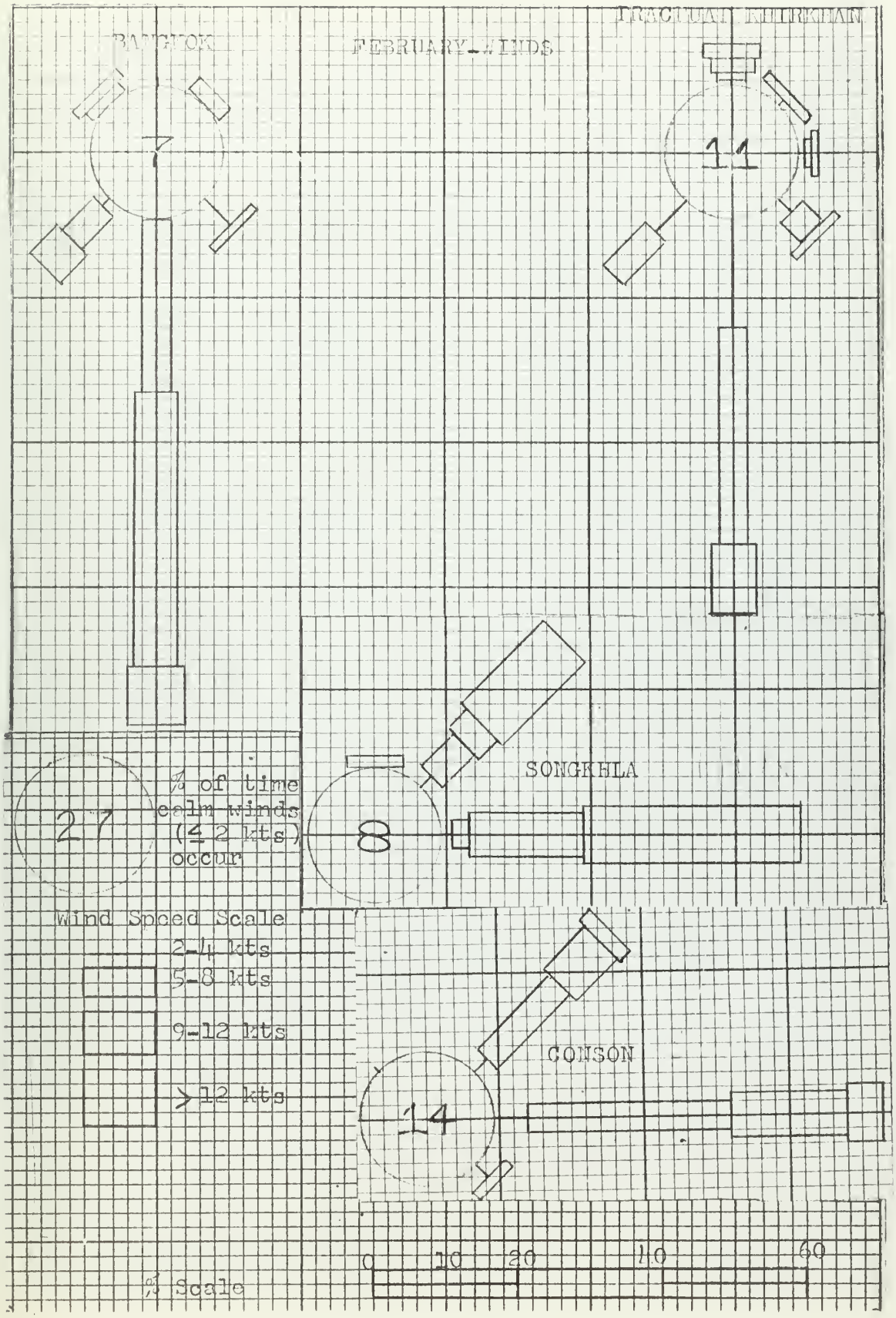


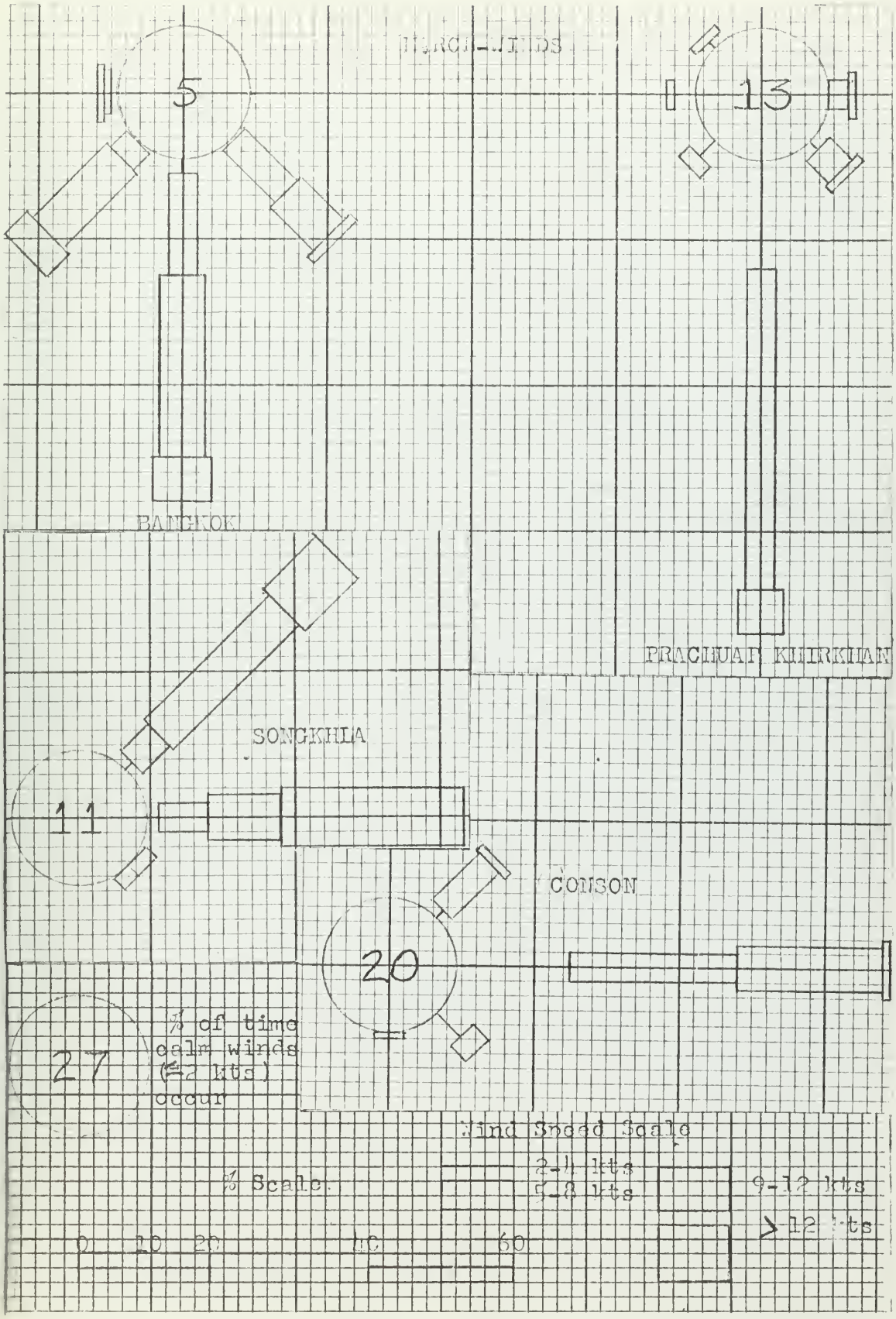
Figure 7. Mean Annual Wind Speeds in the Gulf of Siam, 1950-1957
Compiled from Three-Day Samples per Month.

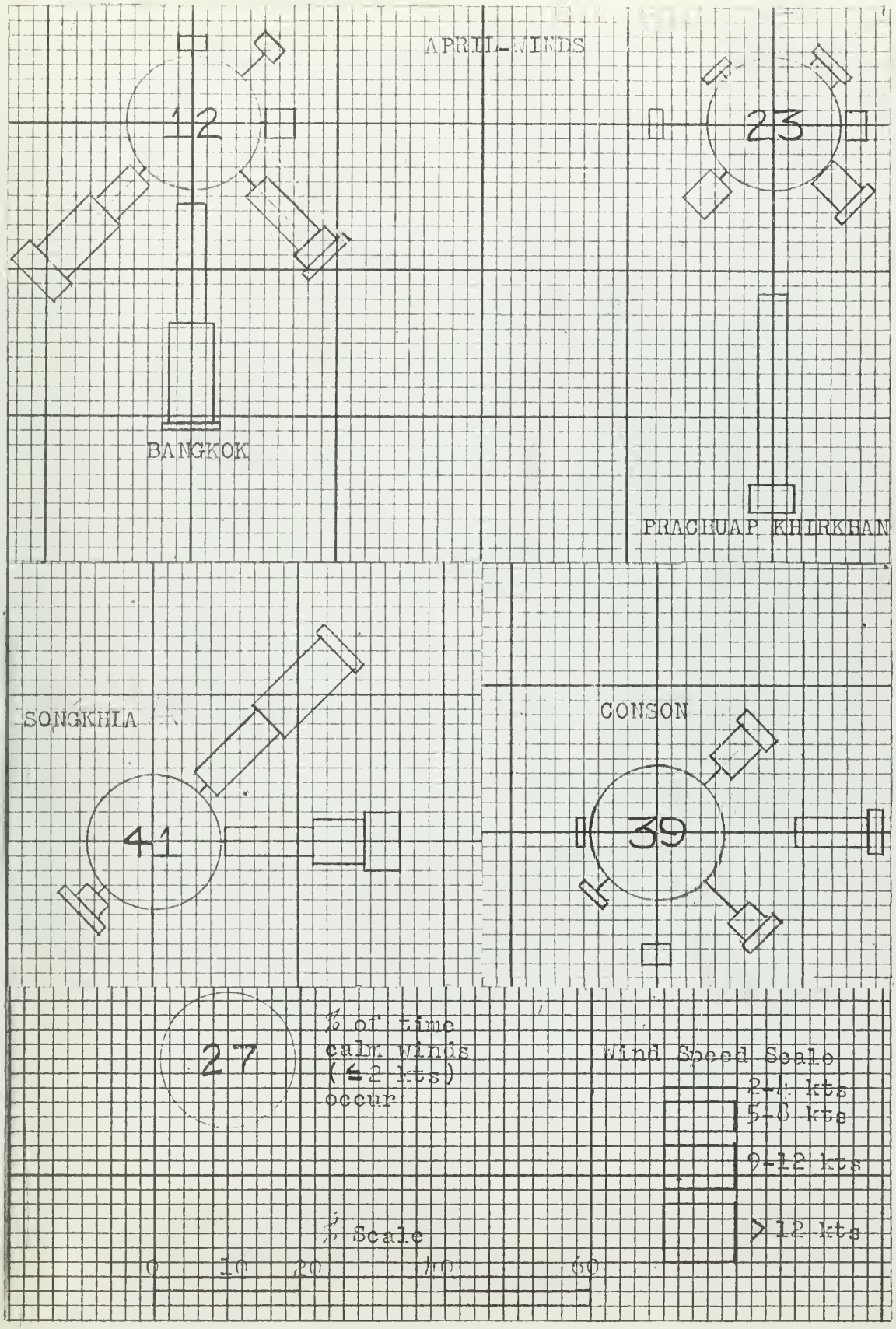
APPENDIX I

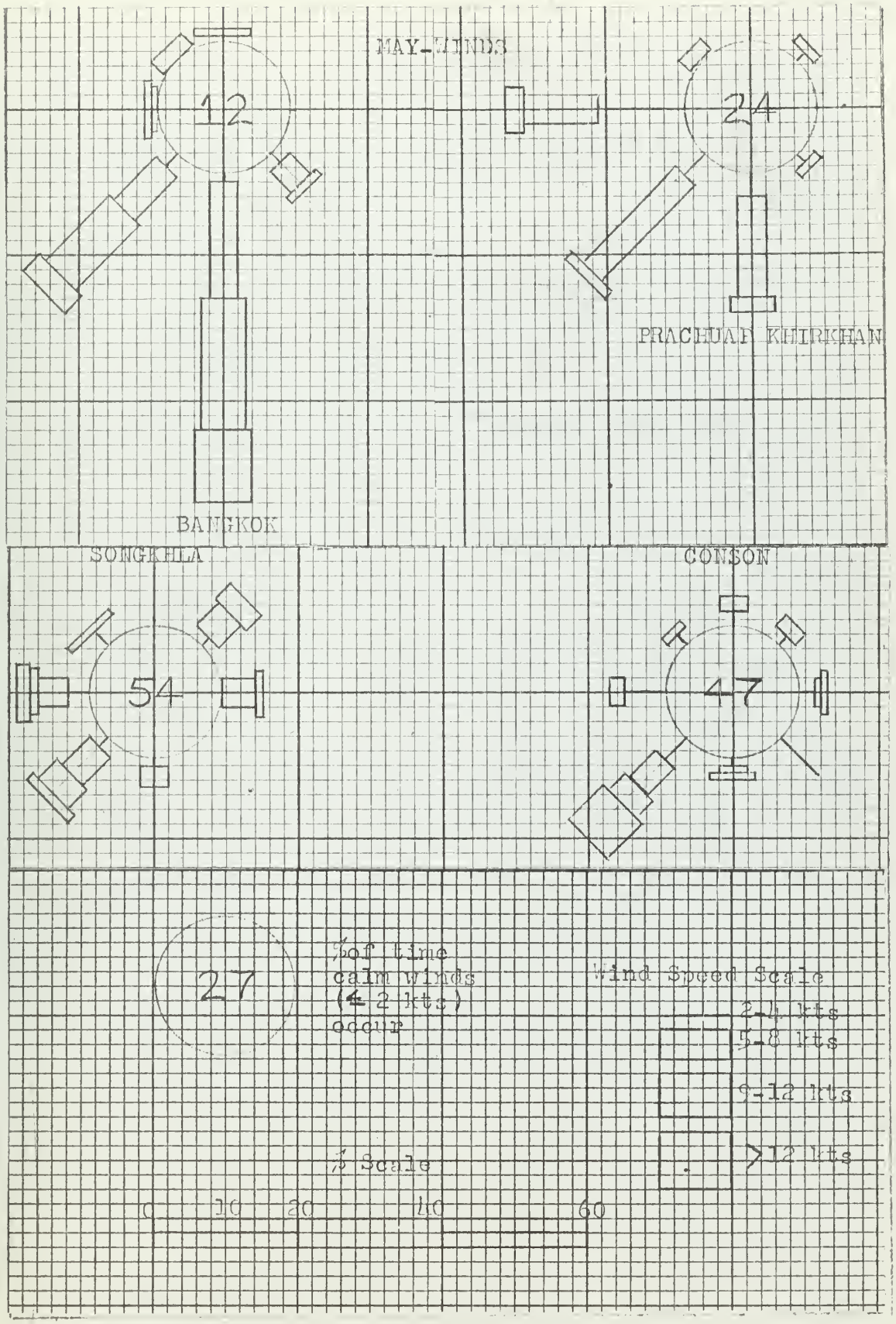
MONTHLY WIND ROSES FOR FOUR STATIONS

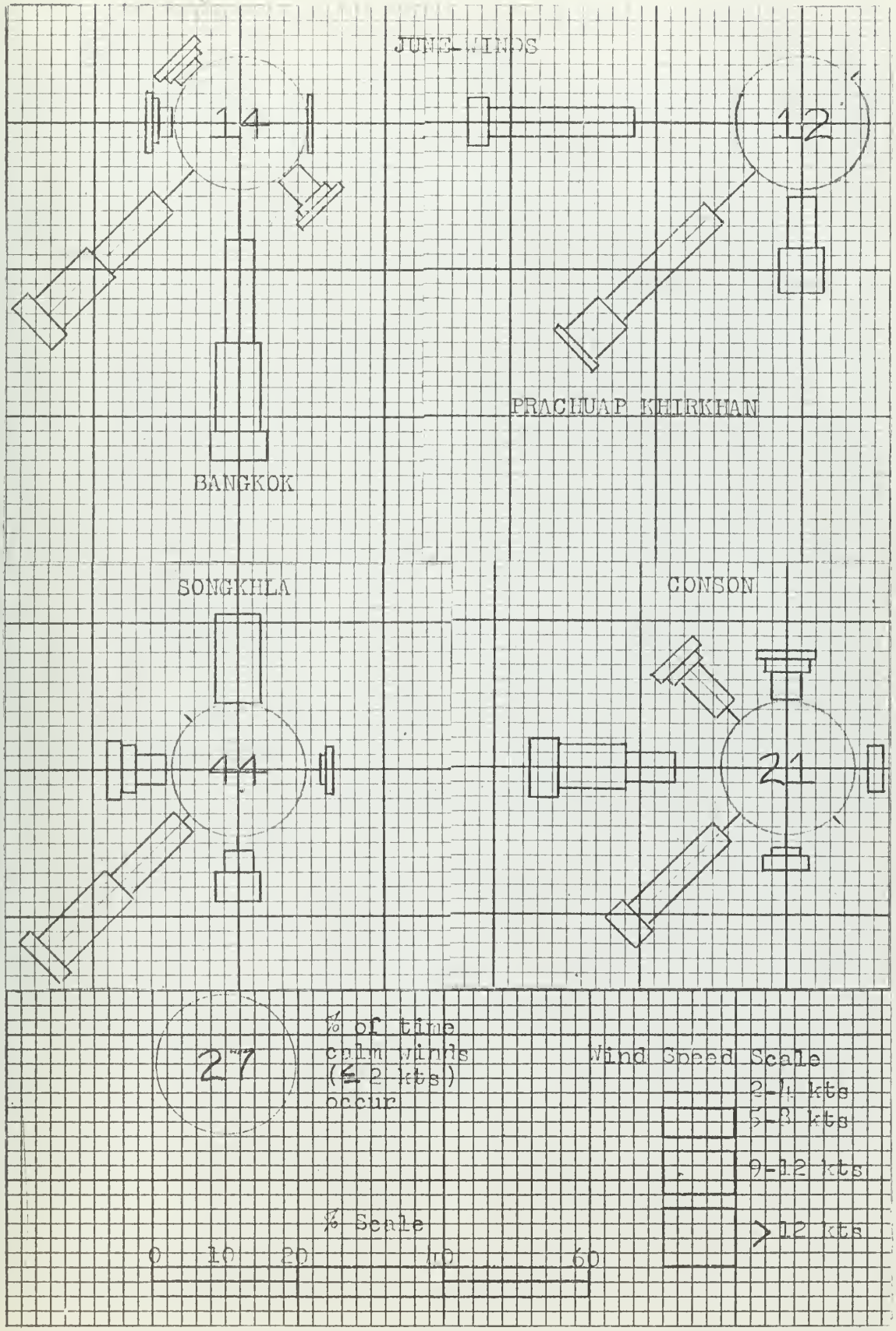

JANUARY - FEBS
BANGKOK
14
27
PRACHUAP KHIRKHAN
SONGKHLA
4
CONSON
14
27
% of time
calm winds
(≤ 2 kts)
occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
> 12 kts
% Scale
0
20
40
60

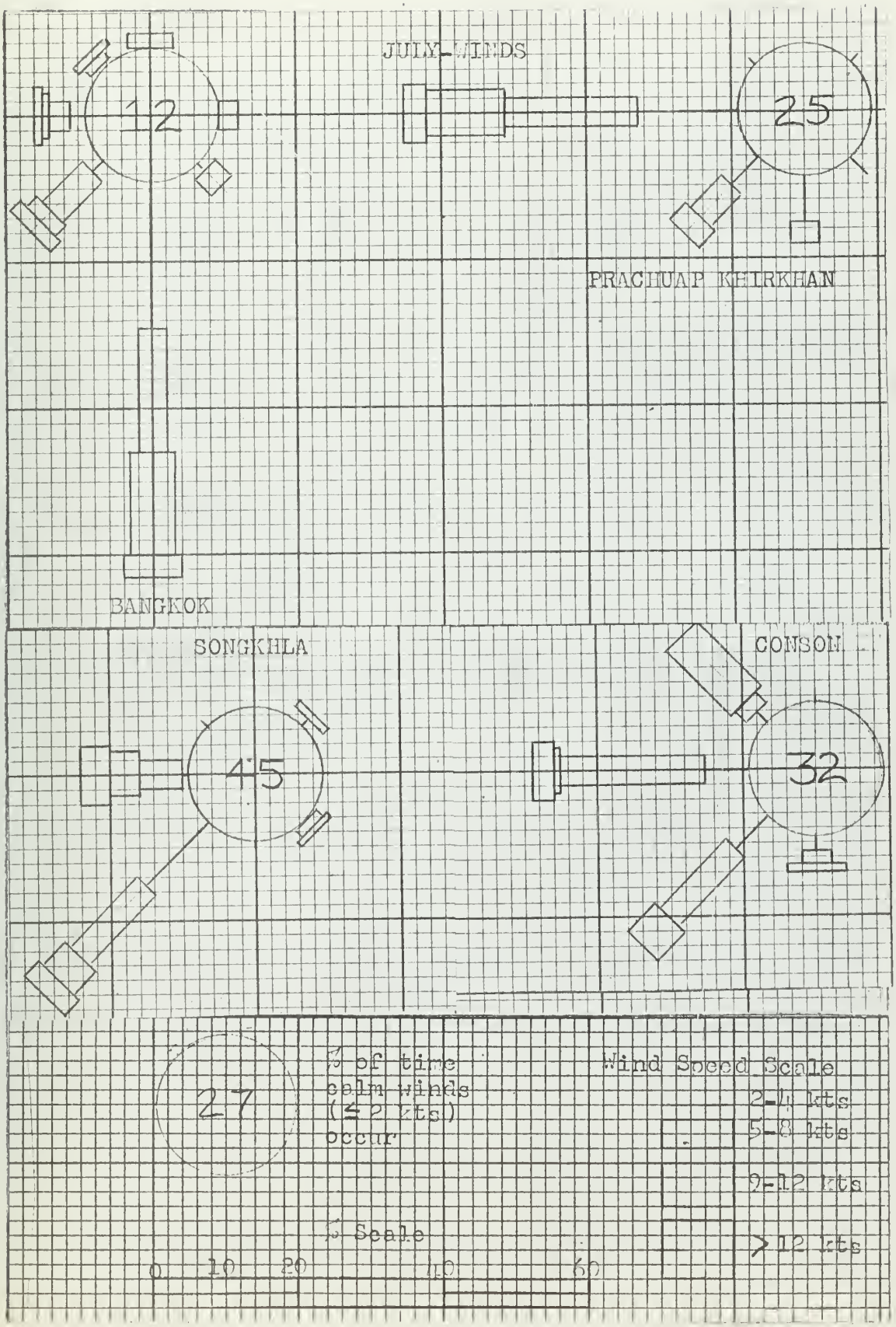

BANGKOK
FEBRUARY WINDS
PRACHUAP KHIRKHAN
7
11
SONGKHLA
8
27
% of time calm winds (≤2 kts) occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
> 12 kts
CONSON
14
0
10
20
40
60
% Scale

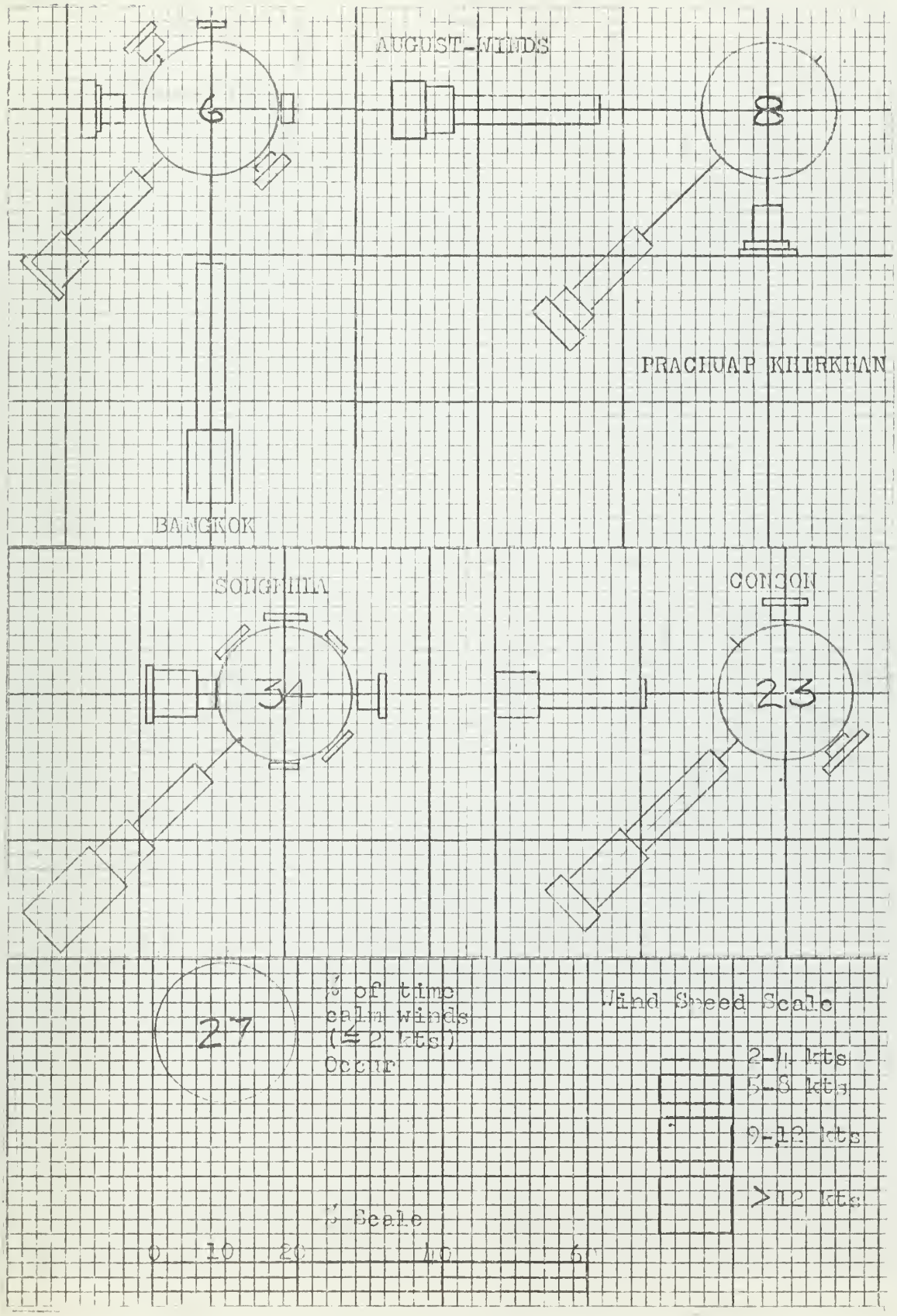

MARCH-WINDS
5
13
BANGKOK
PRACHUAP KHIRKHAN
SONGKHLA
11
CONSON
20
27
% of time calm winds (≤2 kts) occur
Wind Speed Scale
% Scale
2-4 kts
5-8 kts
9-12 kts
>12 kts
0
20
40
60

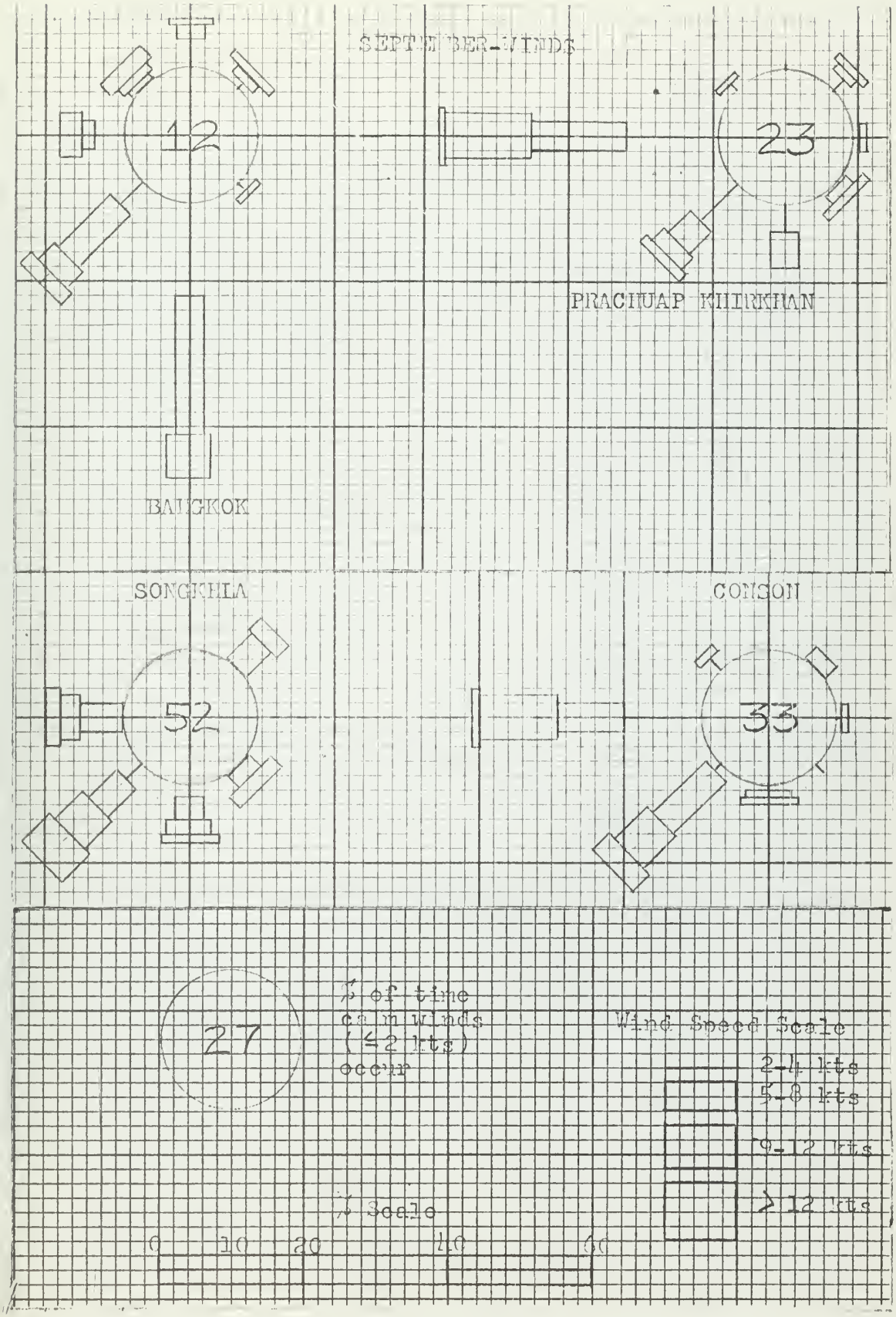

APRIL WINDS
12
BANGKOK
23
PRACHUAP KHIRKHAN
SONGKHLA
41
CONSON
39
27
% of time calm winds (≤2 kts) occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
> 12 kts
% Scale
0
10
20
40
60

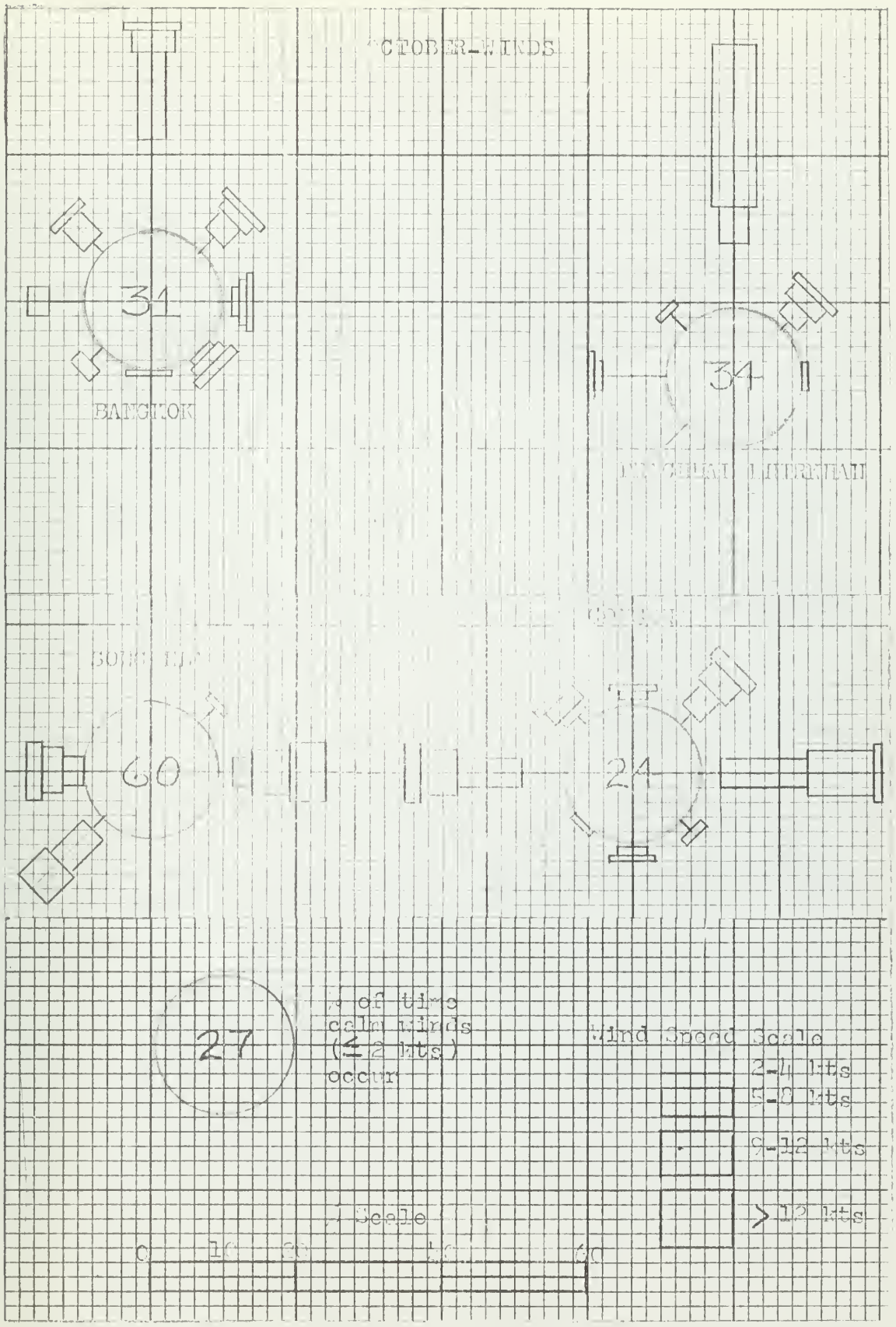

MAY-WINDS
12
24
PRACHUAP KHIRKHAN
BANGKOK
SONGKHLA
CONSON
54
47
27
% of time
calm winds
(≤ 2 kts)
occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
>12 kts
% Scale
0
10
20
40
60

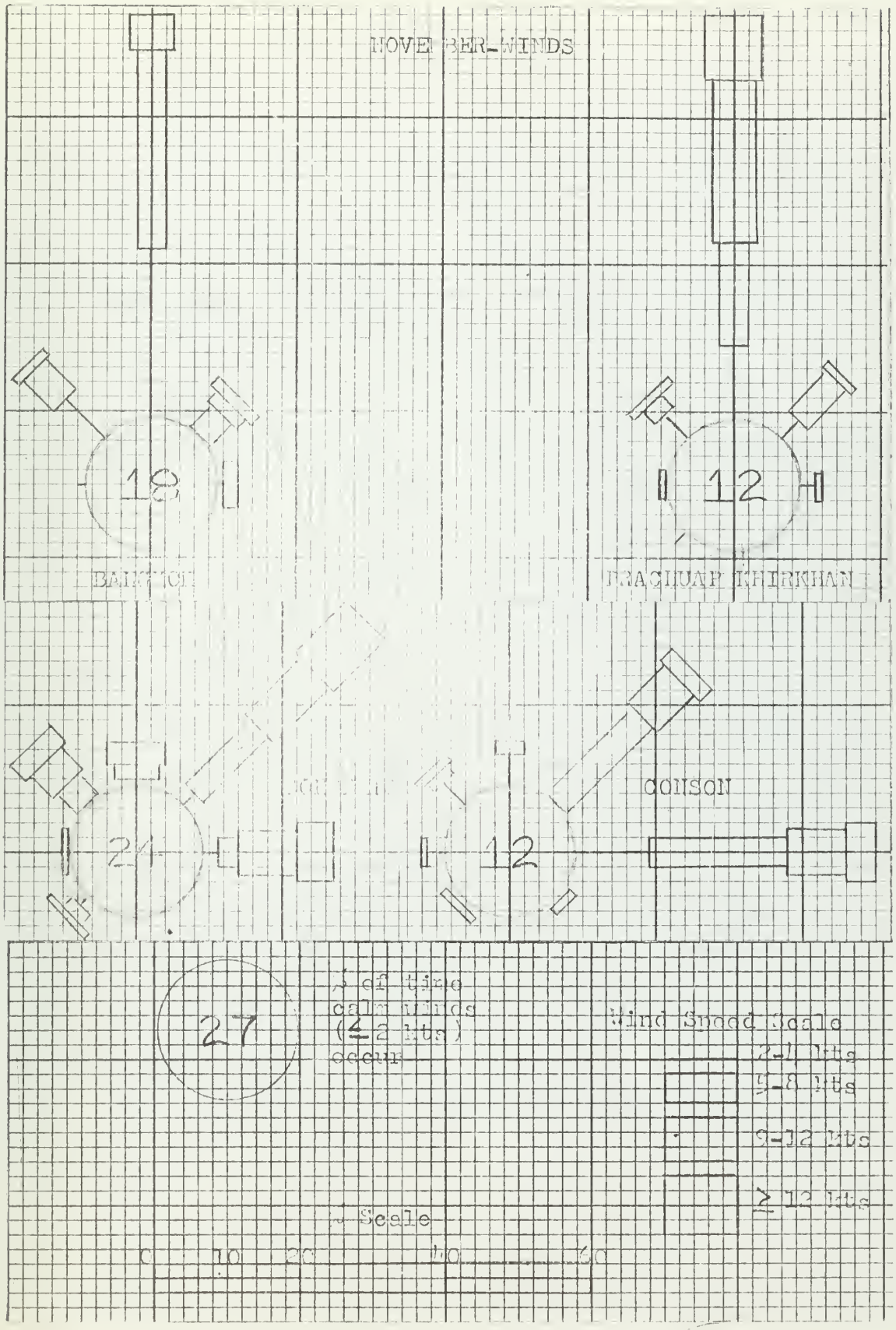

JUNE WINDS
14
BANGKOK
12
PRACHUAP KHIRKHAN
SONGKHLA
44
CONSON
21
27
% of time calm winds (≤ 2 kts) occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
>12 kts
% Scale
0
10
20
40
60

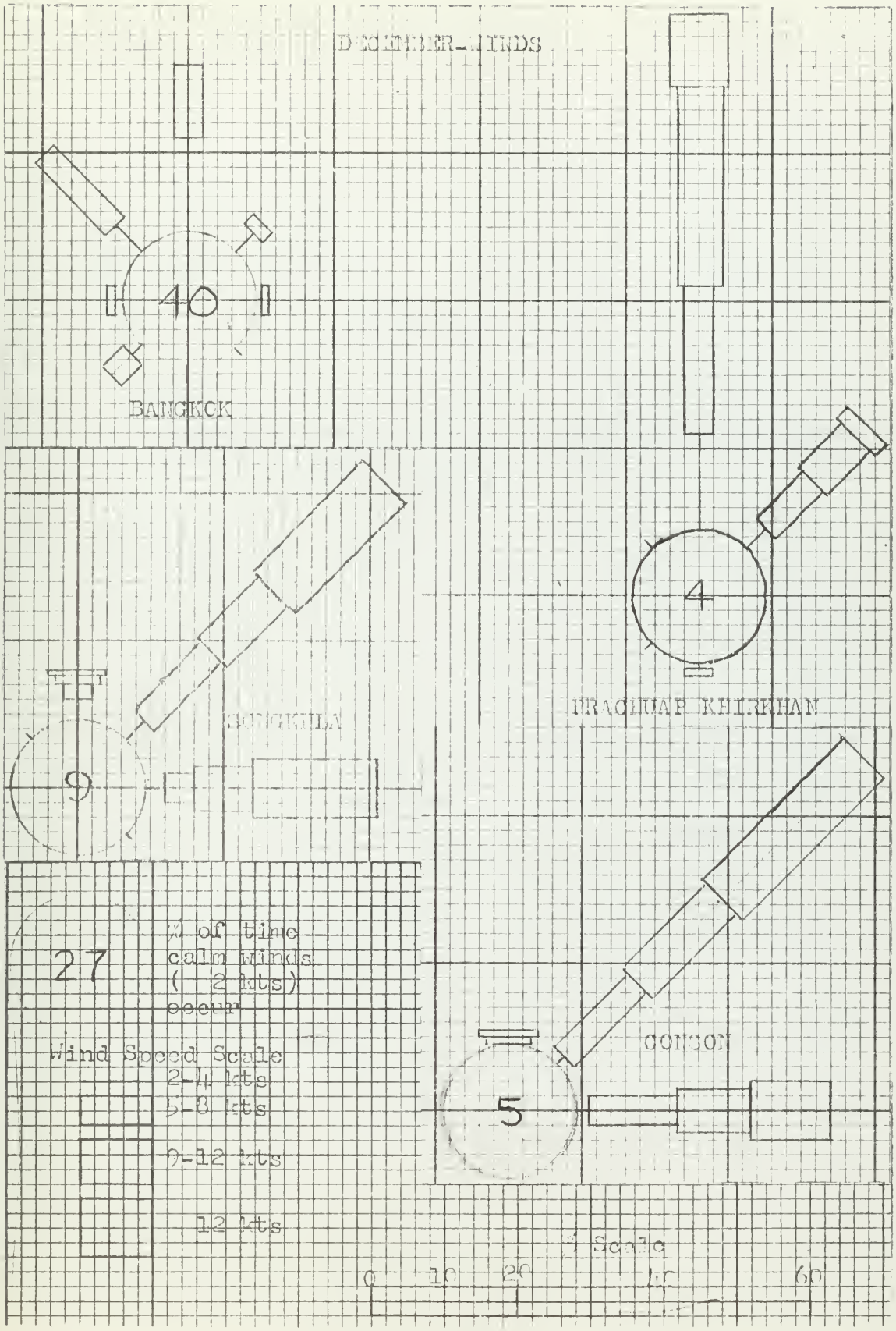

JULY WINDS
12
25
PRACHUAP KHIRKHAN
BANGKOK
SONGKHLA
CONSON
45
32
27
% of time calm winds (≤ 2 kts) occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
> 12 kts
% Scale
0
10
20
40
60


AUGUST-WINDS
6
8
PRACHUAP KHIRKHAN
BANGKOK
SONGHKLA
CONSON
34
23
27
% of time
calm winds
(≤ 2 kts)
Occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
>12 kts
% Scale
0 10 20 40 60


SEPTEMBER-WINDS
12
23
PRACHUAP KHIRKHAN
BANGKOK
SONGKHLA
CONSON
52
33
27
% of time
calm winds
(≤2 kts)
occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
>12 kts
% Scale
0
10
20
40
60


OCTOBER-WINDS
34
BANGKOK
34
60
24
27
% of time
calm winds
(≤2 kts)
occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
>12 kts
Scale

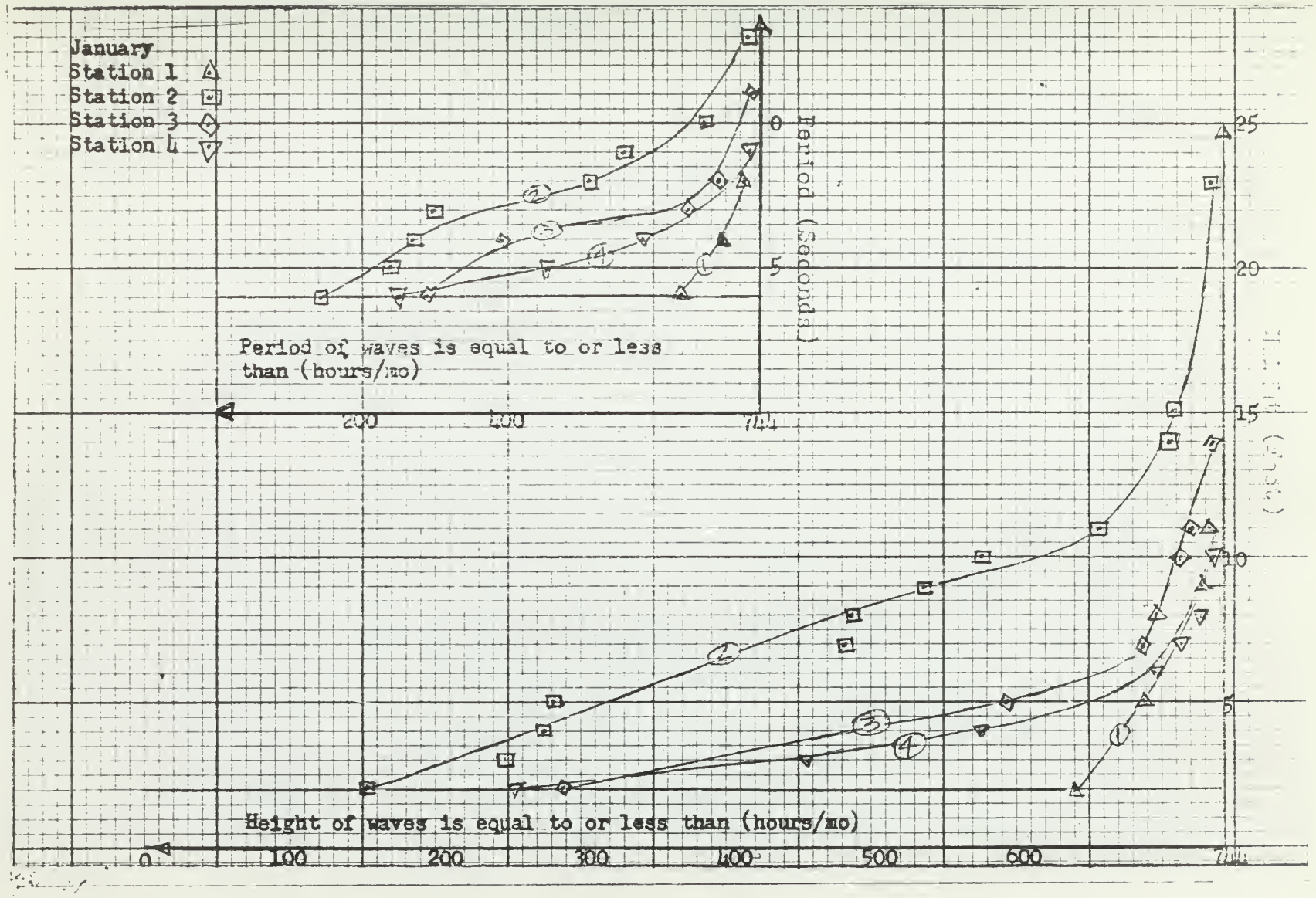

NOVEMBER WINDS
18
12
BAINTON
PRACHUAP KHIRKHAN
24
12
CONSON
27
% of time
calm winds
(≤ 2 kts)
occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
≥ 12 kts
% Scale
0
10
20
30
40

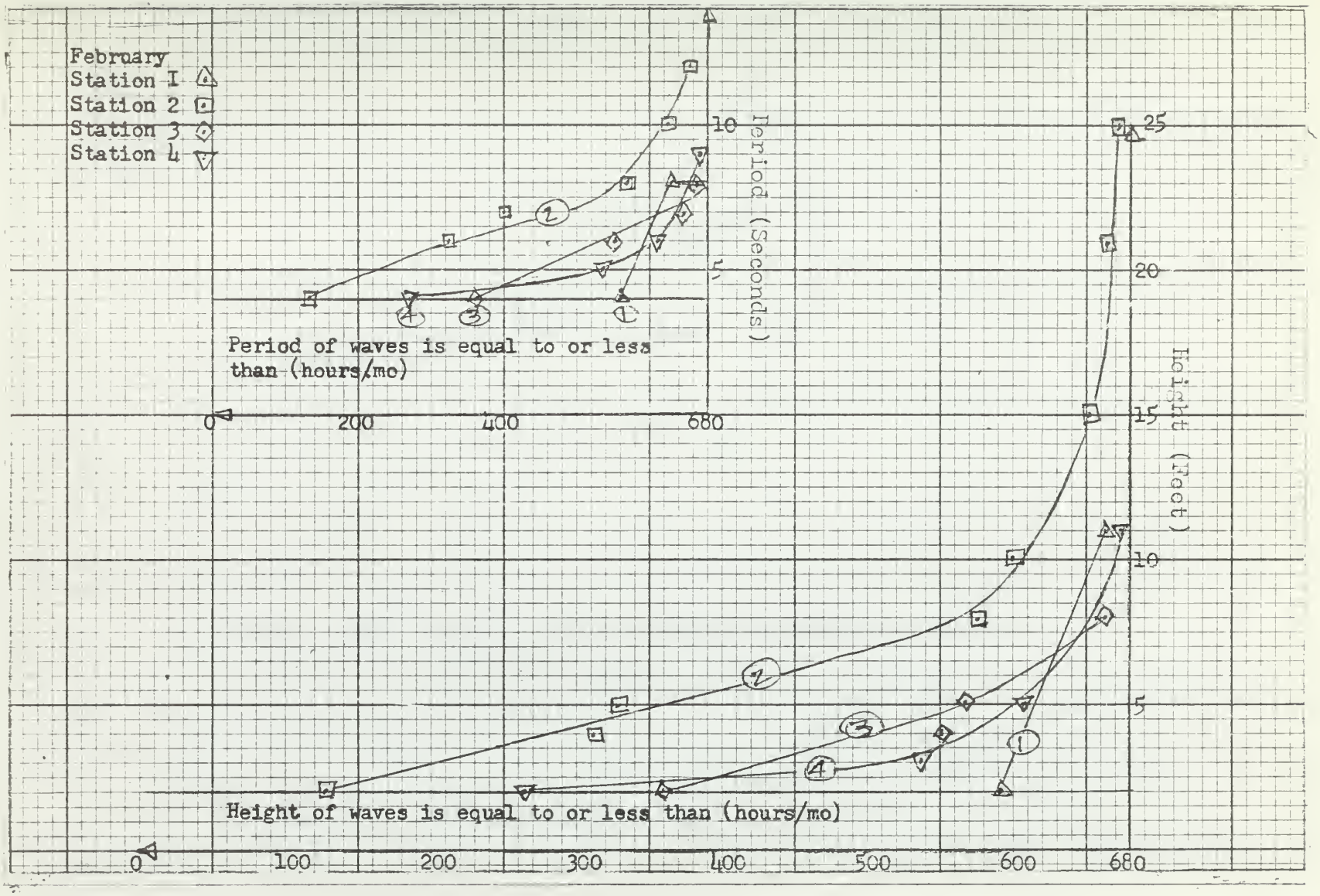

DECEMBER-WINDS
40
BANGKOK
4
PRACHUAP KHIRIHAN
9
27
% of time
calm winds
(2 kts)
occur
Wind Speed Scale
2-4 kts
5-8 kts
9-12 kts
12 kts
CONSON
5
Scale
0
10
20
40
60

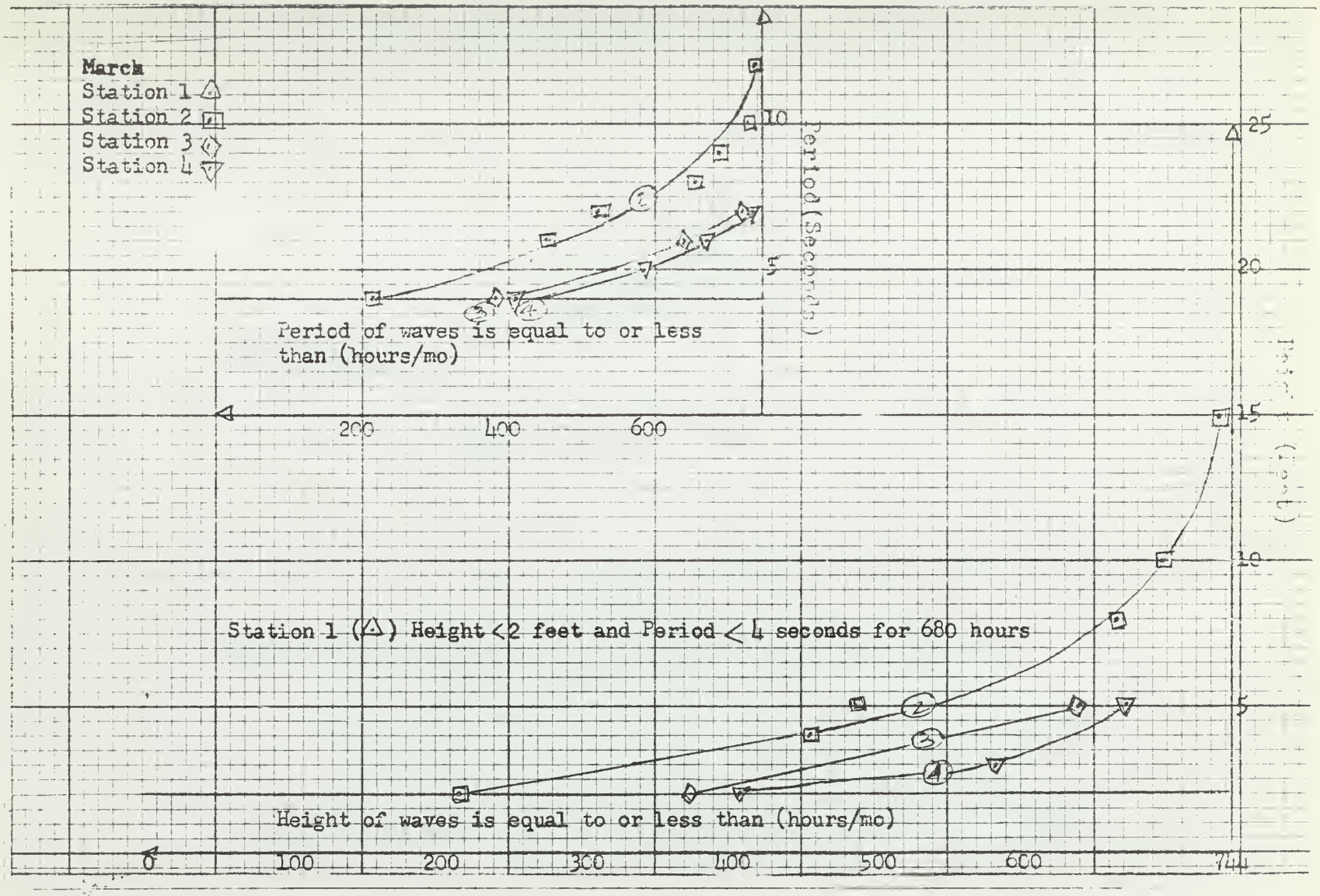
APPENDIX II

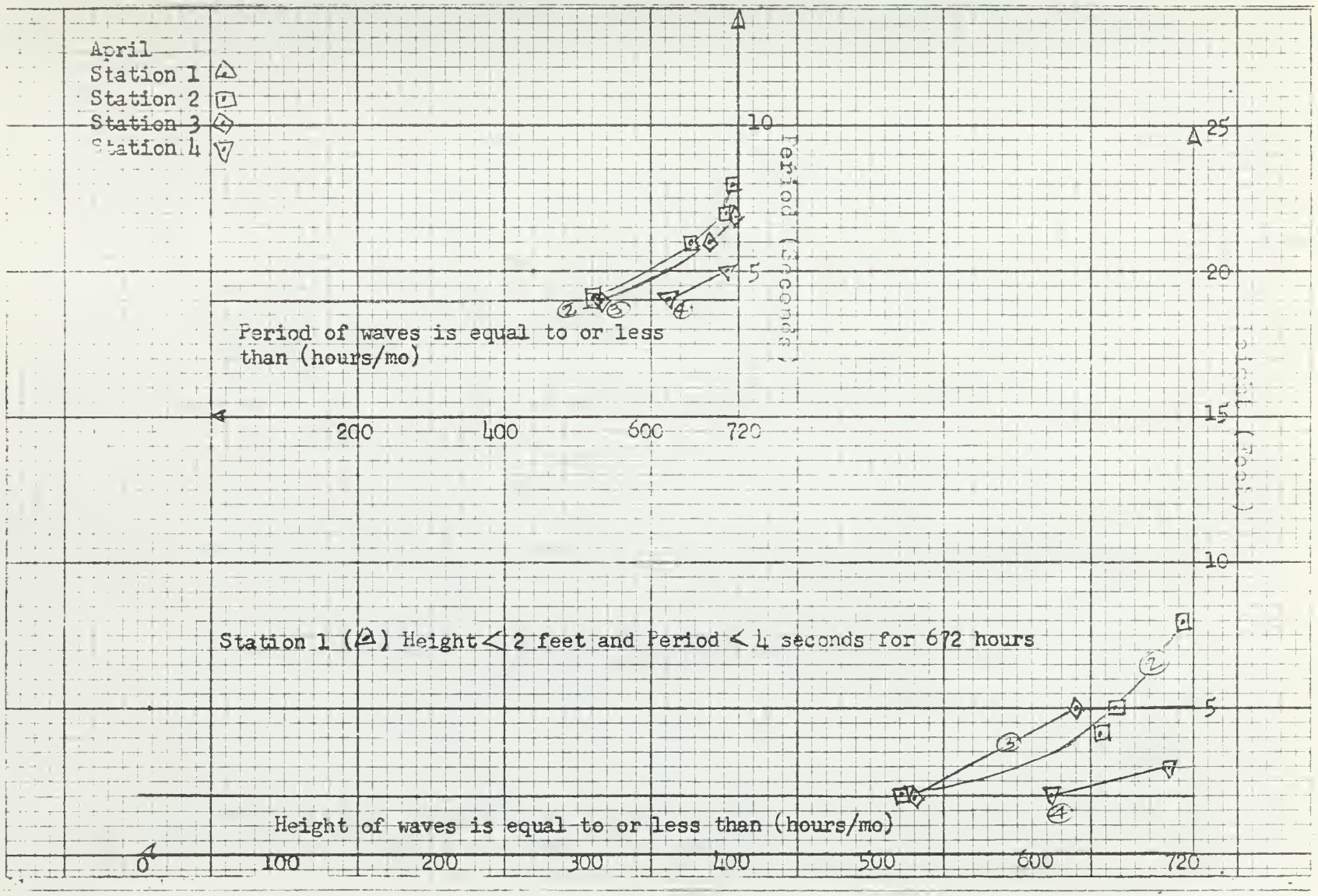
MONTHLY GRAPHS OF WAVE HEIGHT AND WAVE PERIOD

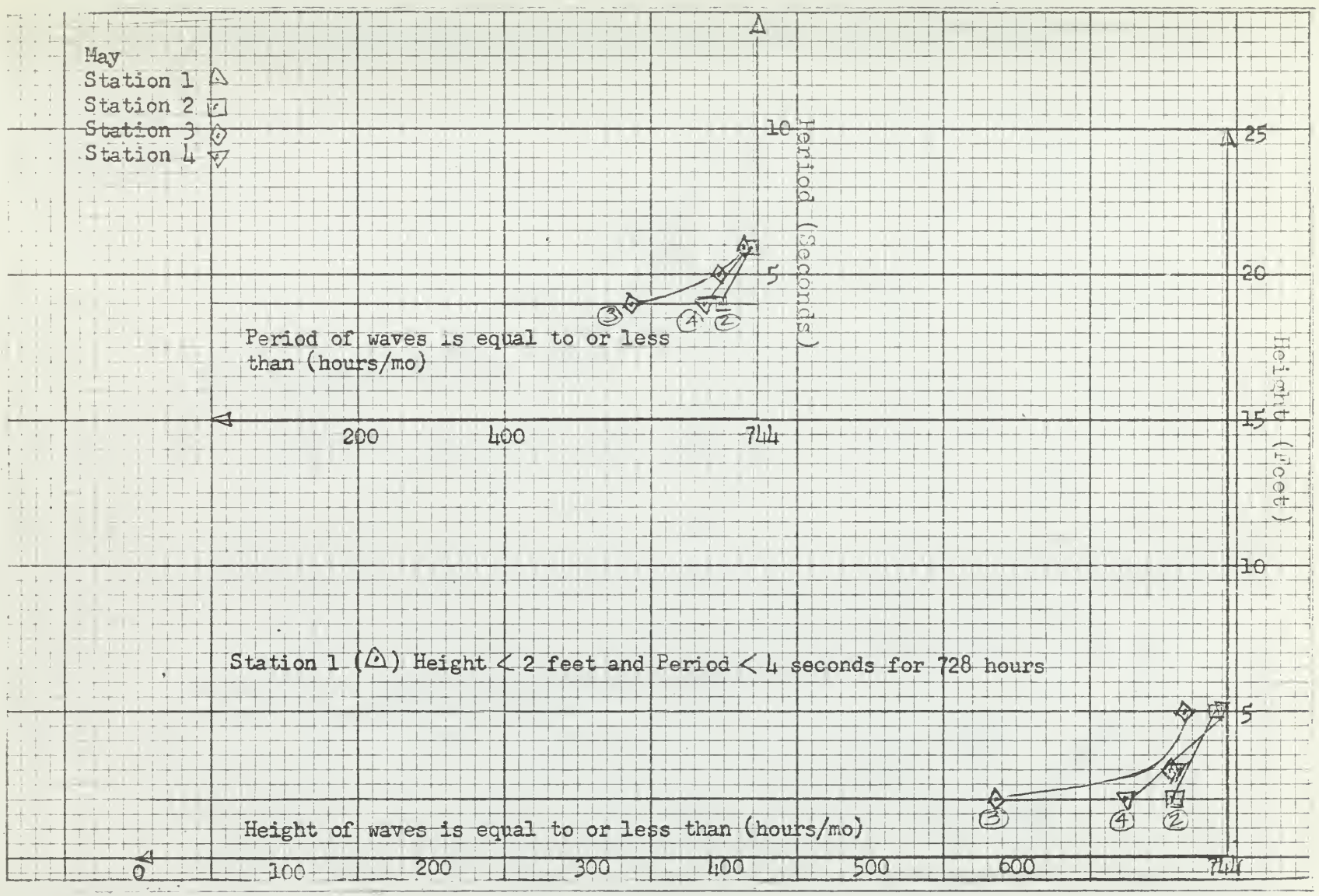
FOR FOUR STATIONS

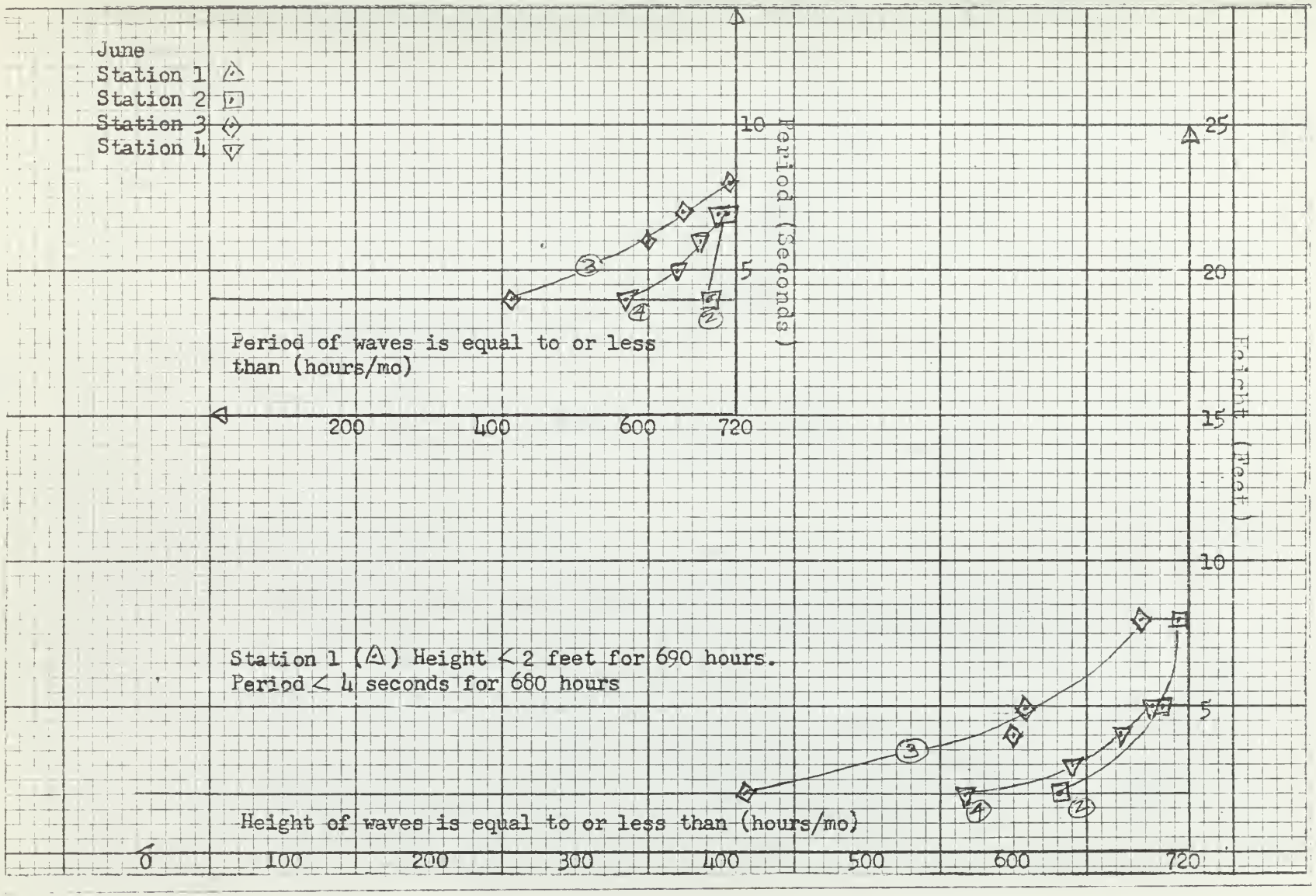

January
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
200
400
744
Period (Seconds)
0
5
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
744
Height (Feet)
5
10
15
20
25

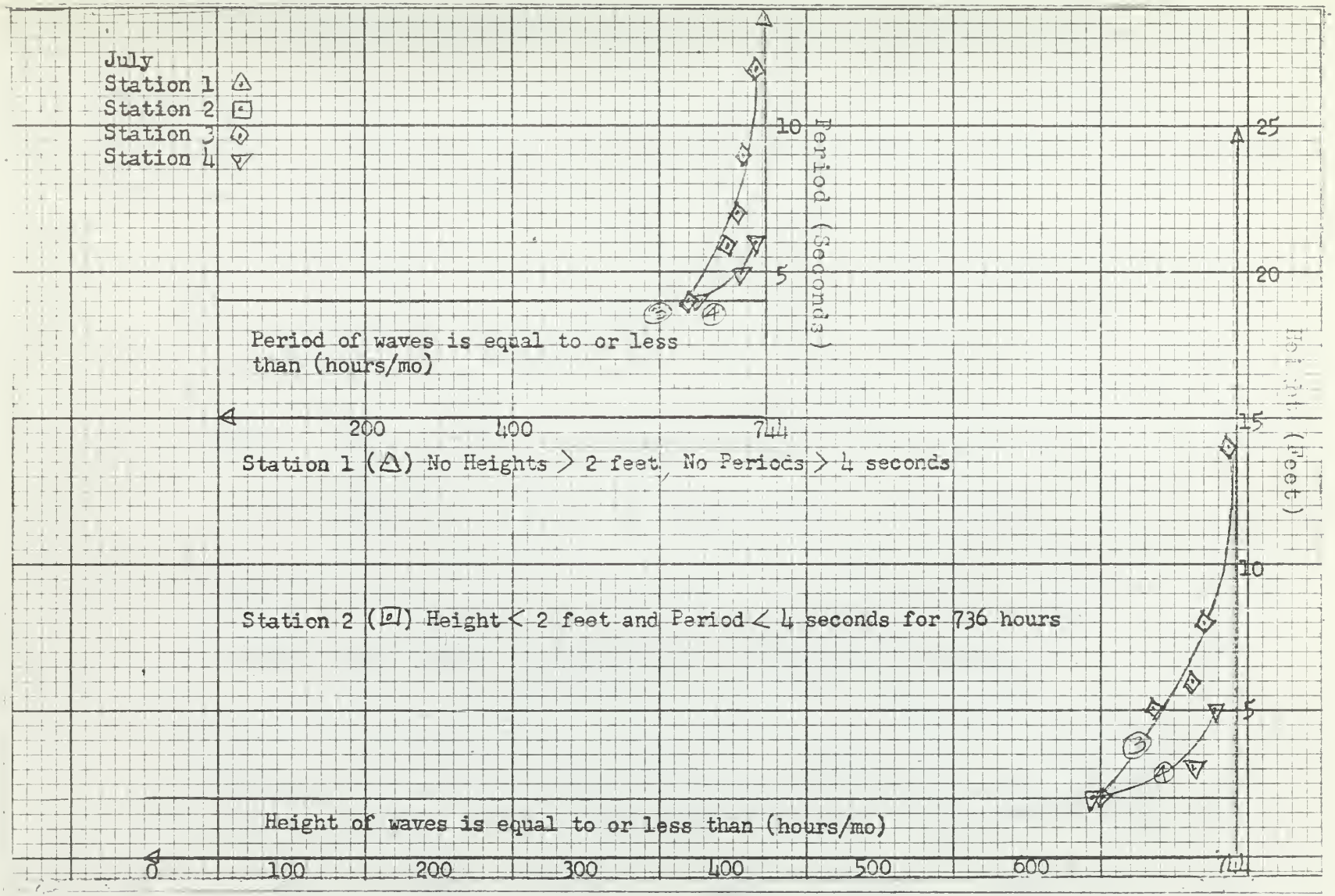

February
Station 1
Station 2
Station 3
Station 4
Period (Seconds)
Height (feet)
Period of waves is equal to or less than (hours/mo)
Height of waves is equal to or less than (hours/mo)
0
200
400
680
10
5
25
20
15
10
5
0
100
200
300
400
500
600
680
1
2
3
4

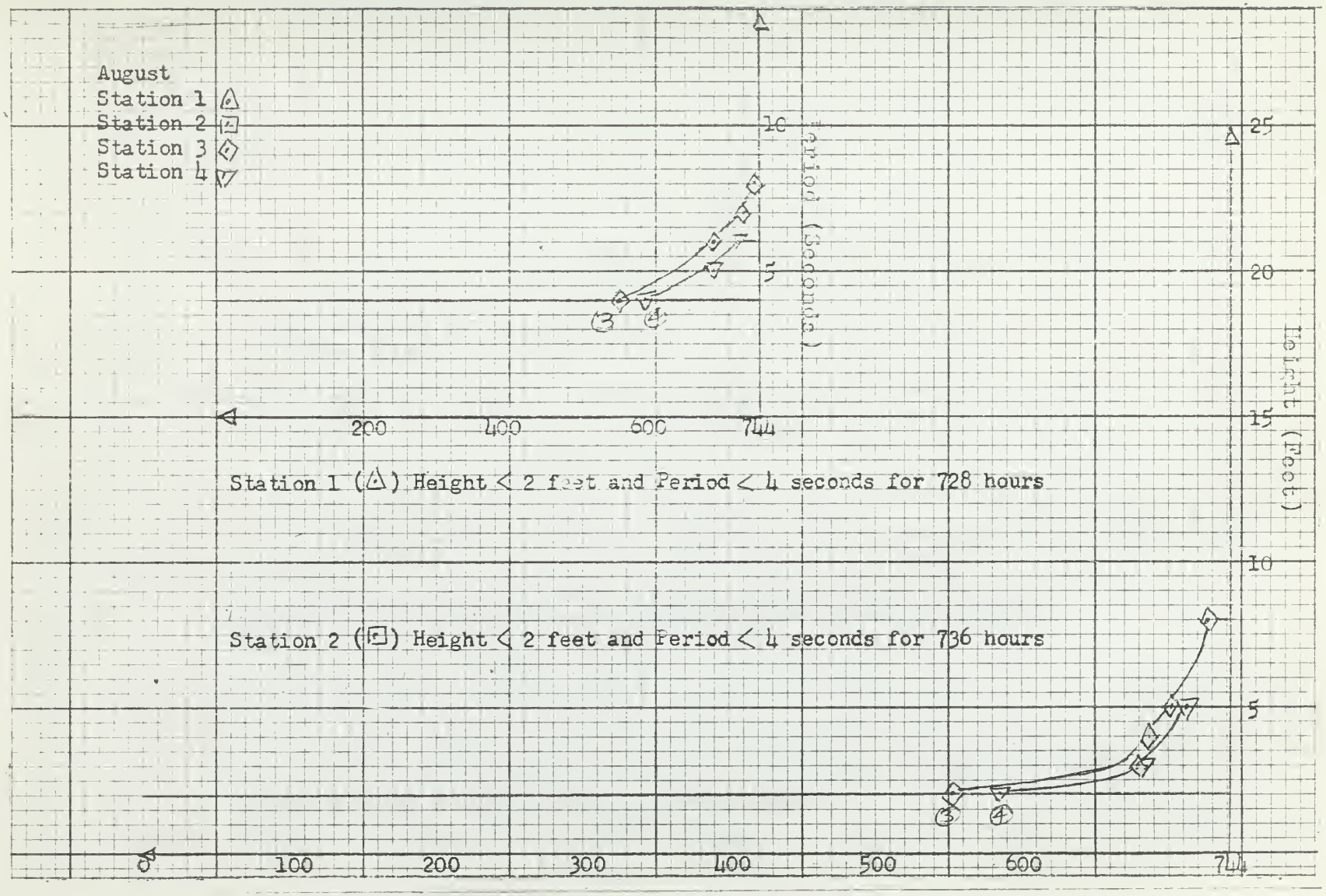

March
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
Period (seconds)
200
400
600
10
5
Station 1 (△) Height < 2 feet and Period < 4 seconds for 680 hours
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
744
25
20
15
10
5
Height (feet)

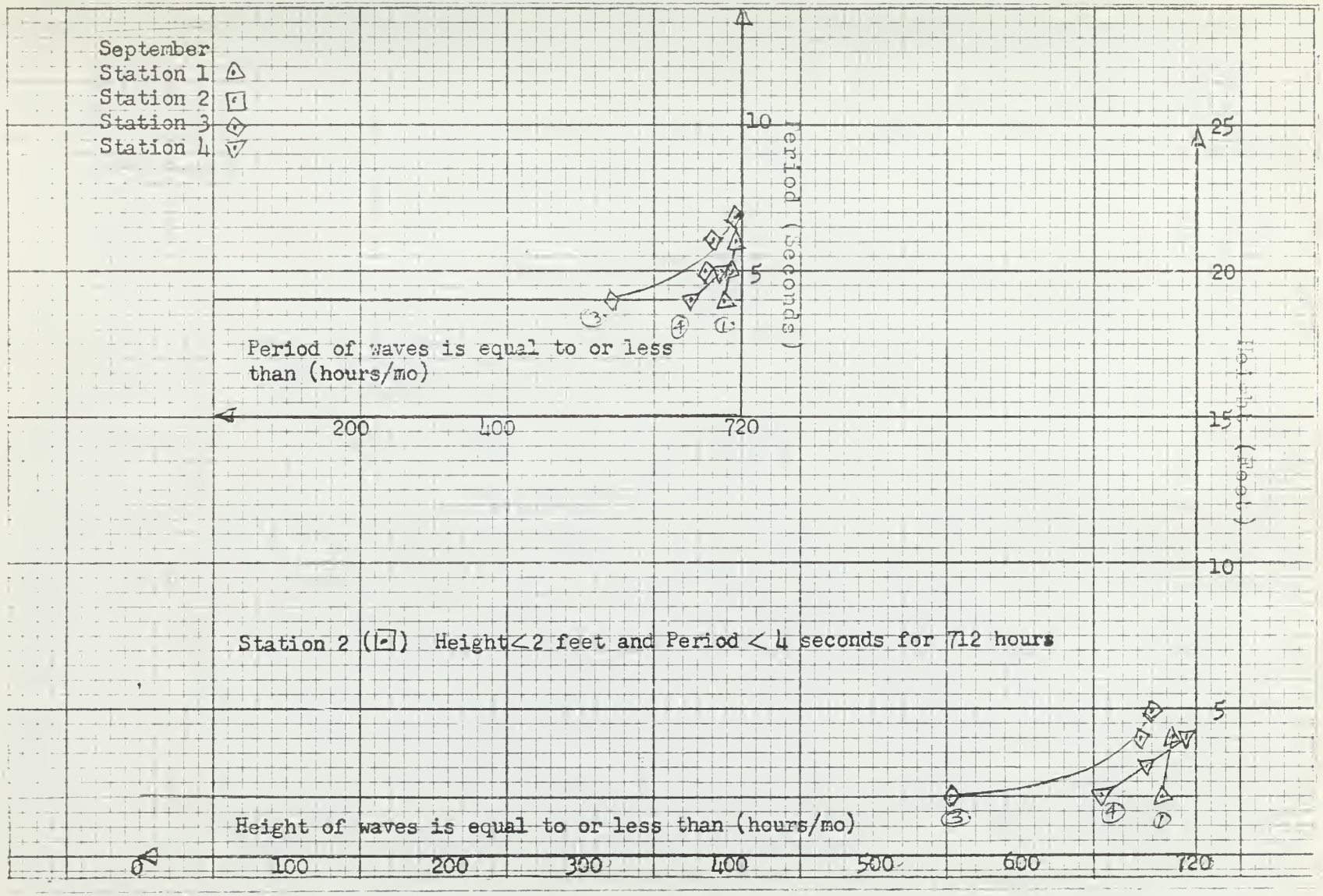

April
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
200
400
600
720
10
5
Period (seconds)
25
20
15
10
5
Station 1 (△) Height < 2 feet and Period < 4 seconds for 672 hours
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
720

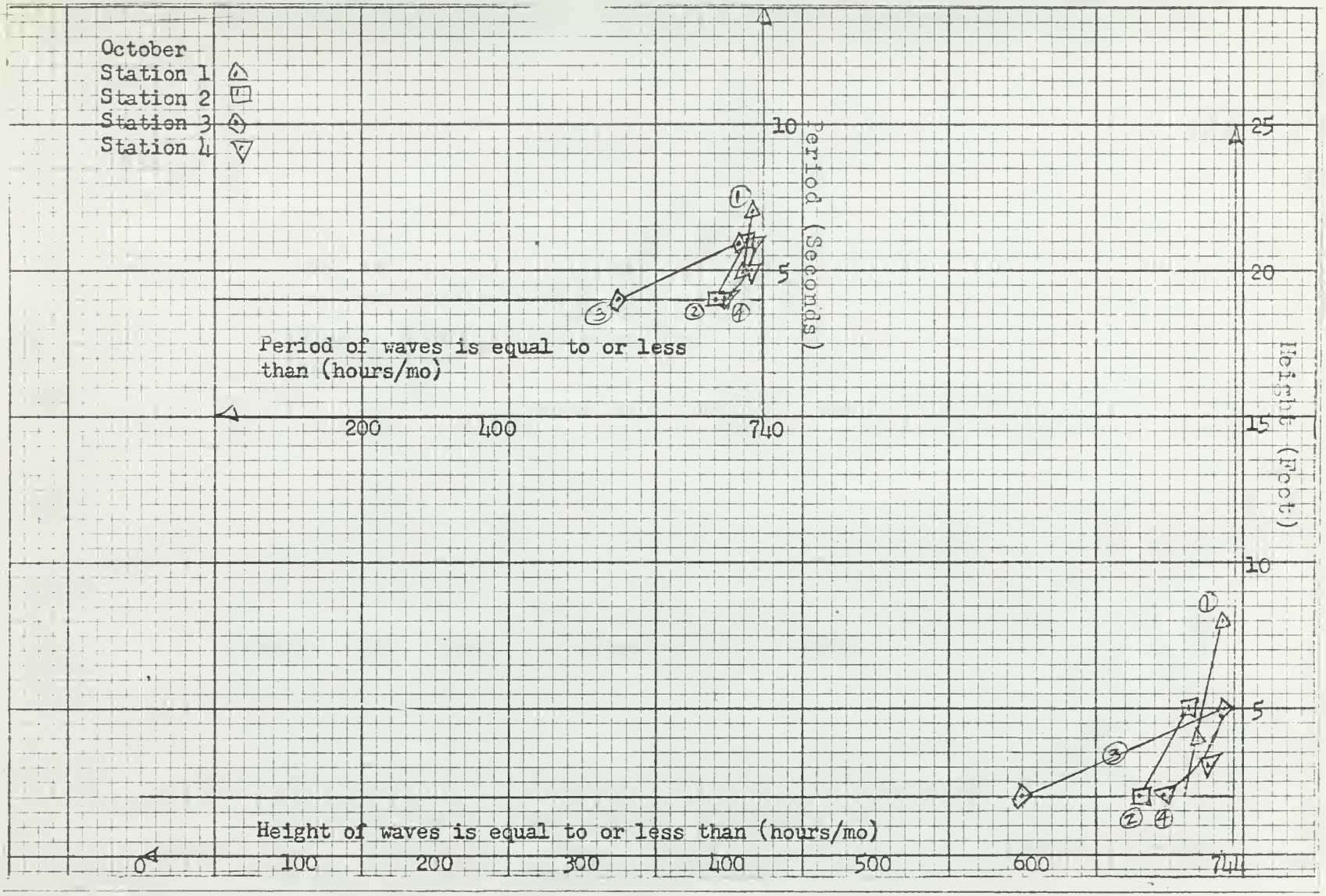

May
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
200
400
744
10
5
Period (Seconds)
25
20
15
10
5
Height (feet)
Station 1 (△) Height < 2 feet and Period < 4 seconds for 728 hours
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
744

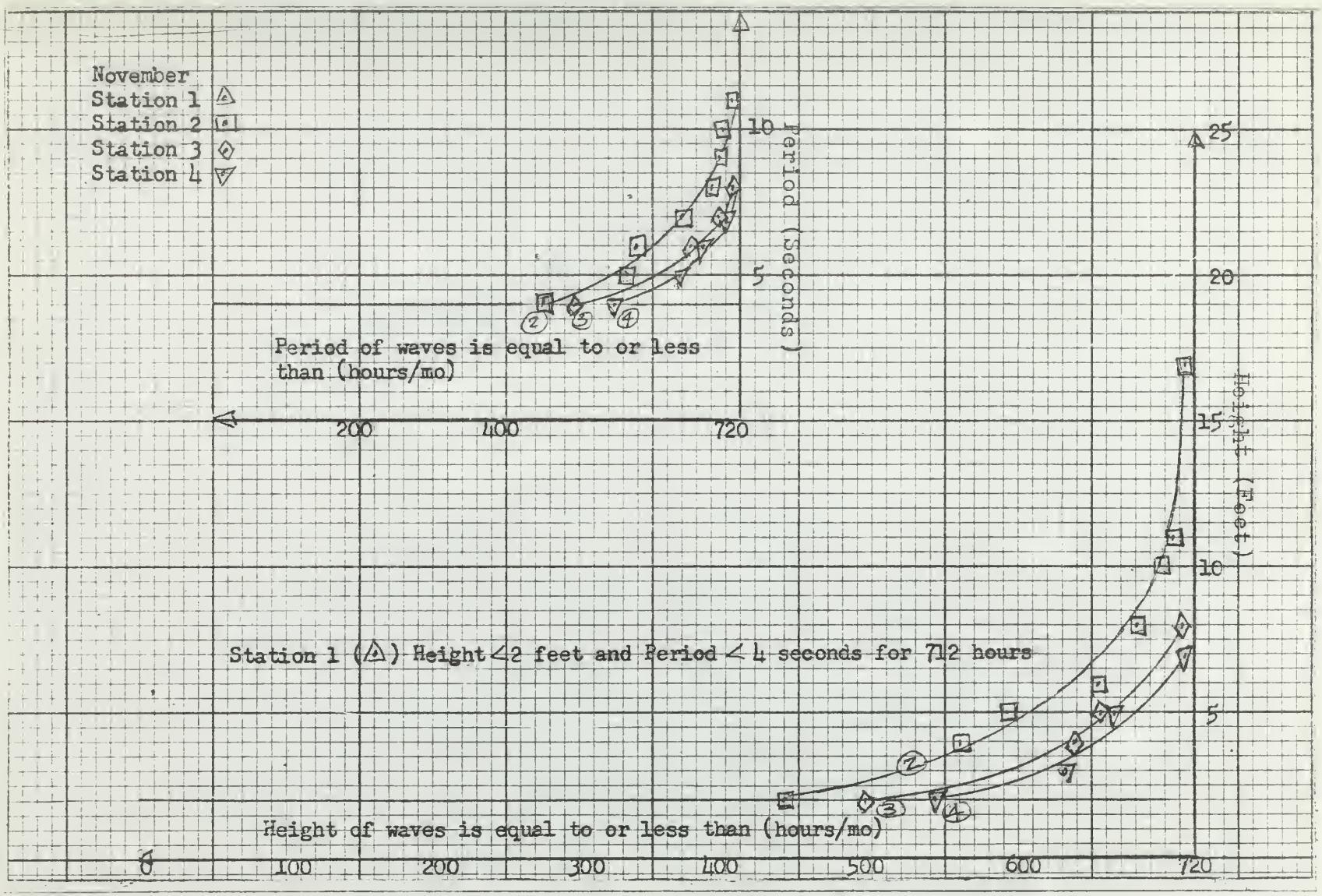

June
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
200
400
600
720
10
5
Period (Seconds)
Station 1 (△) Height < 2 feet for 690 hours.
Period < 4 seconds for 680 hours
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
720
25
20
15
10
5
Height (Feet)

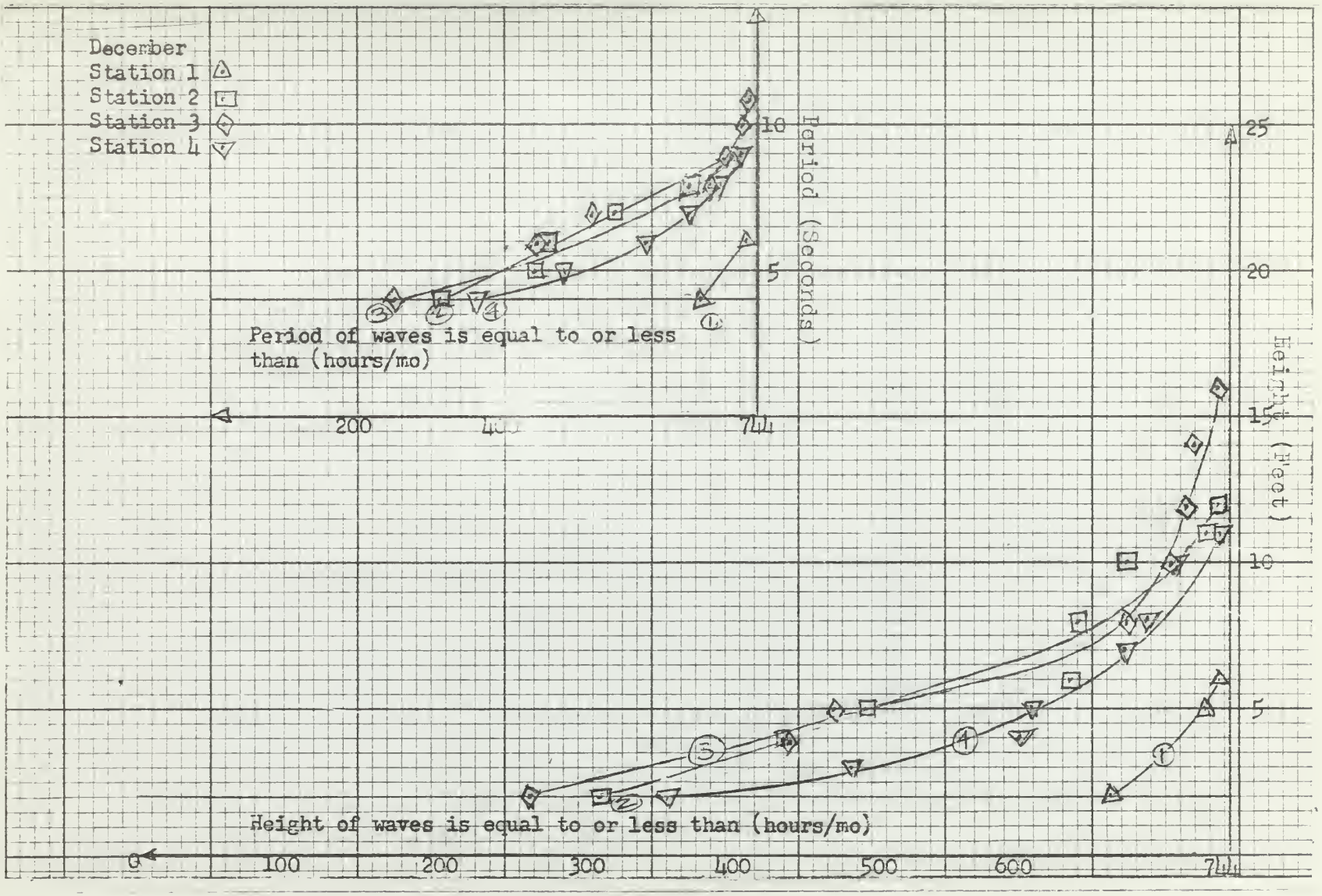

July
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
200
400
744
Station 1 (△) No Heights > 2 feet, No Periods > 4 seconds
Station 2 (⊡) Height < 2 feet and Period < 4 seconds for 736 hours
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
744
5
10
Period (Seconds)
5
10
15
20
25
Height (Feet)


August
Station 1
Station 2
Station 3
Station 4
Period (Seconds)
Height (Feet)
10
5
25
20
15
10
5
200
400
600
744
100
200
300
400
500
600
744
Station 1 (△) Height < 2 feet and Period < 4 seconds for 728 hours
Station 2 (⊡) Height < 2 feet and Period < 4 seconds for 736 hours


September
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
200
400
720
10
5
Period (seconds)
Station 2 (⊡) Height < 2 feet and Period < 4 seconds for 712 hours
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
720
25
20
15
10
5
Height (feet)

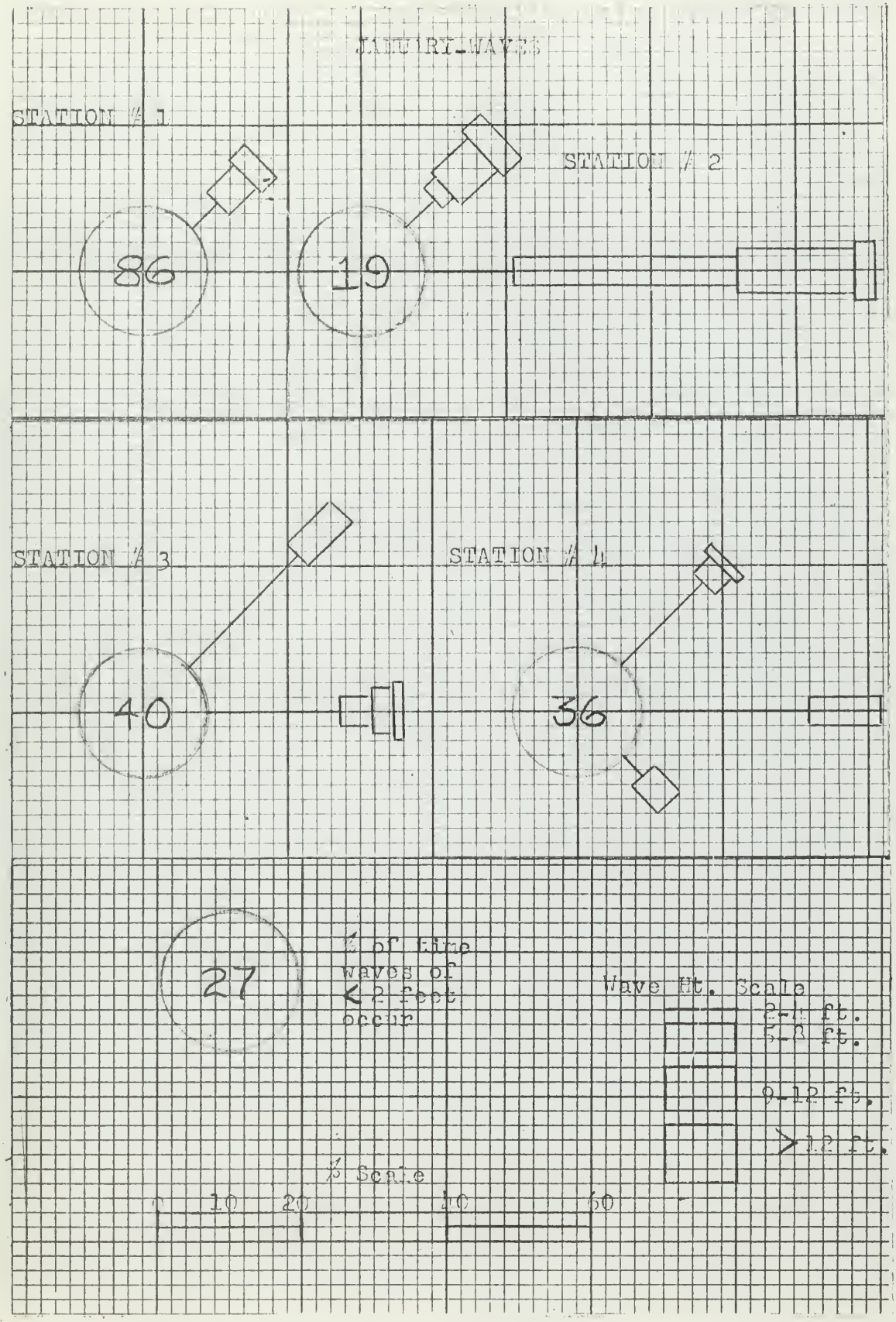

October
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
200
400
740
10
5
Period (Seconds)
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
744
25
20
15
10
5
Height (Feet)

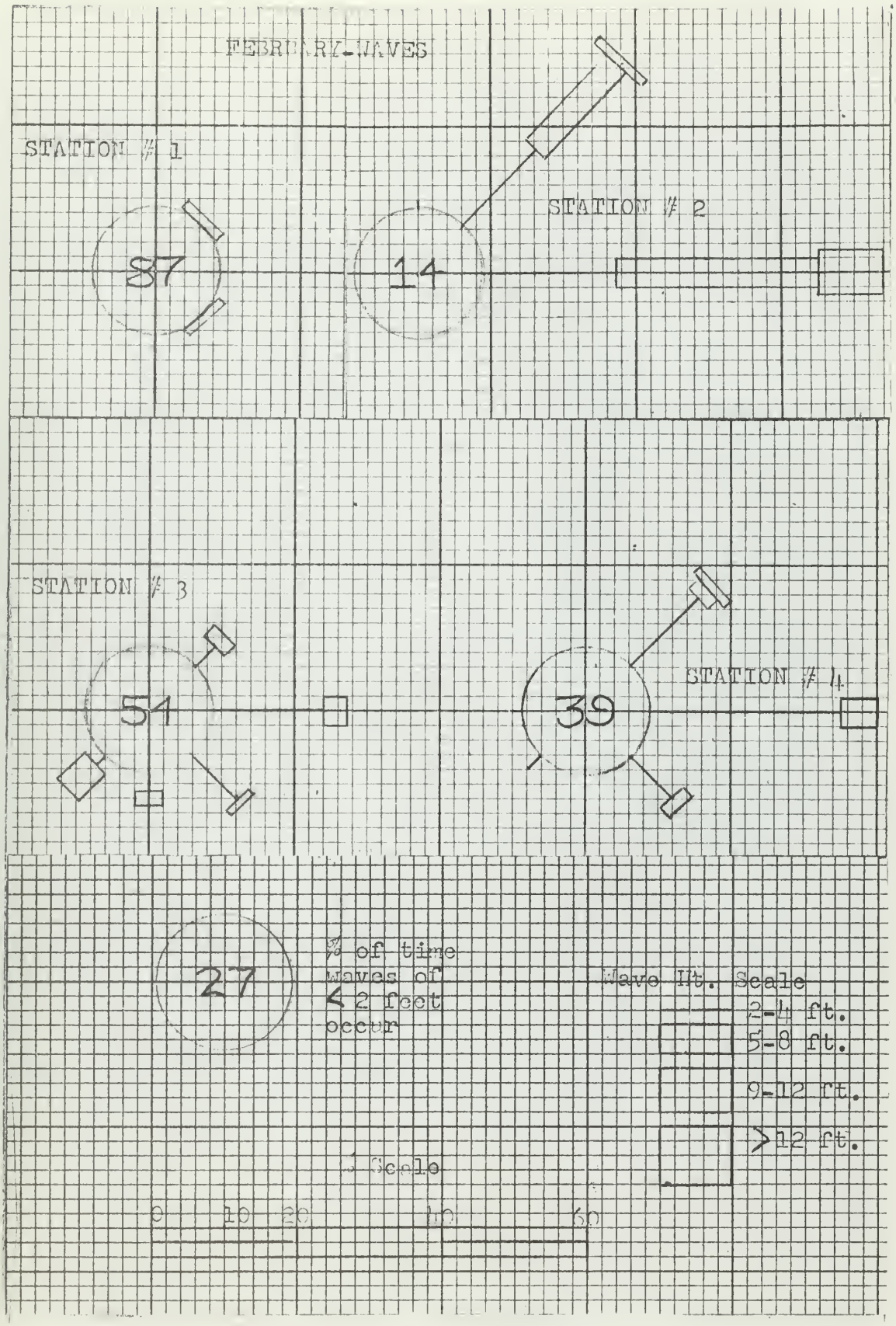

November
Station 1
Station 2
Station 3
Station 4
Period (Seconds)
10
5
Period of waves is equal to or less than (hours/mo)
200
400
720
Height (Feet)
25
20
15
10
5
Station 1 (△) Height < 2 feet and Period < 4 seconds for 712 hours
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
720

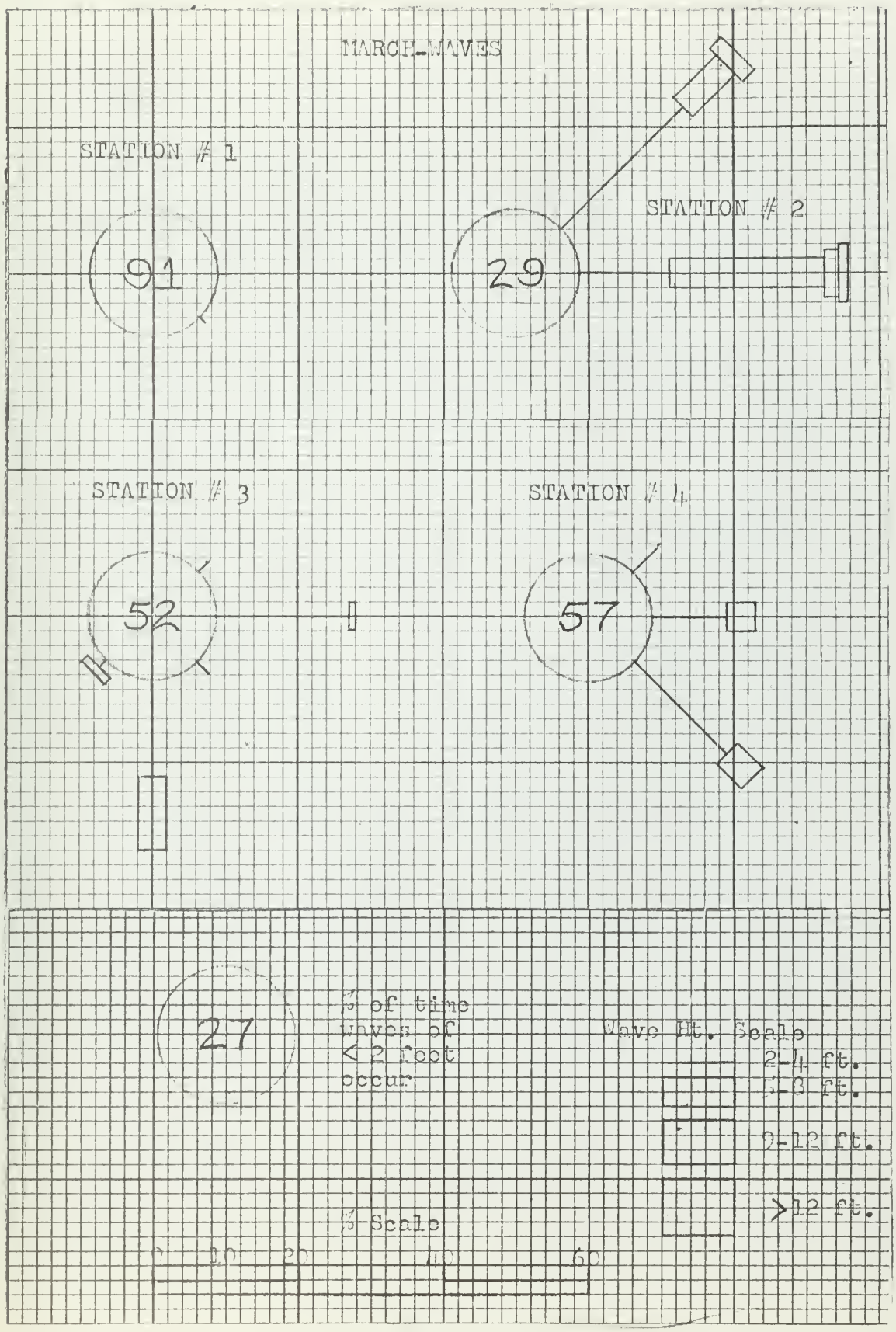

December
Station 1
Station 2
Station 3
Station 4
Period of waves is equal to or less than (hours/mo)
Period (Seconds)
Height (Feet)
Height of waves is equal to or less than (hours/mo)
0
100
200
300
400
500
600
744
5
10
15
20
25

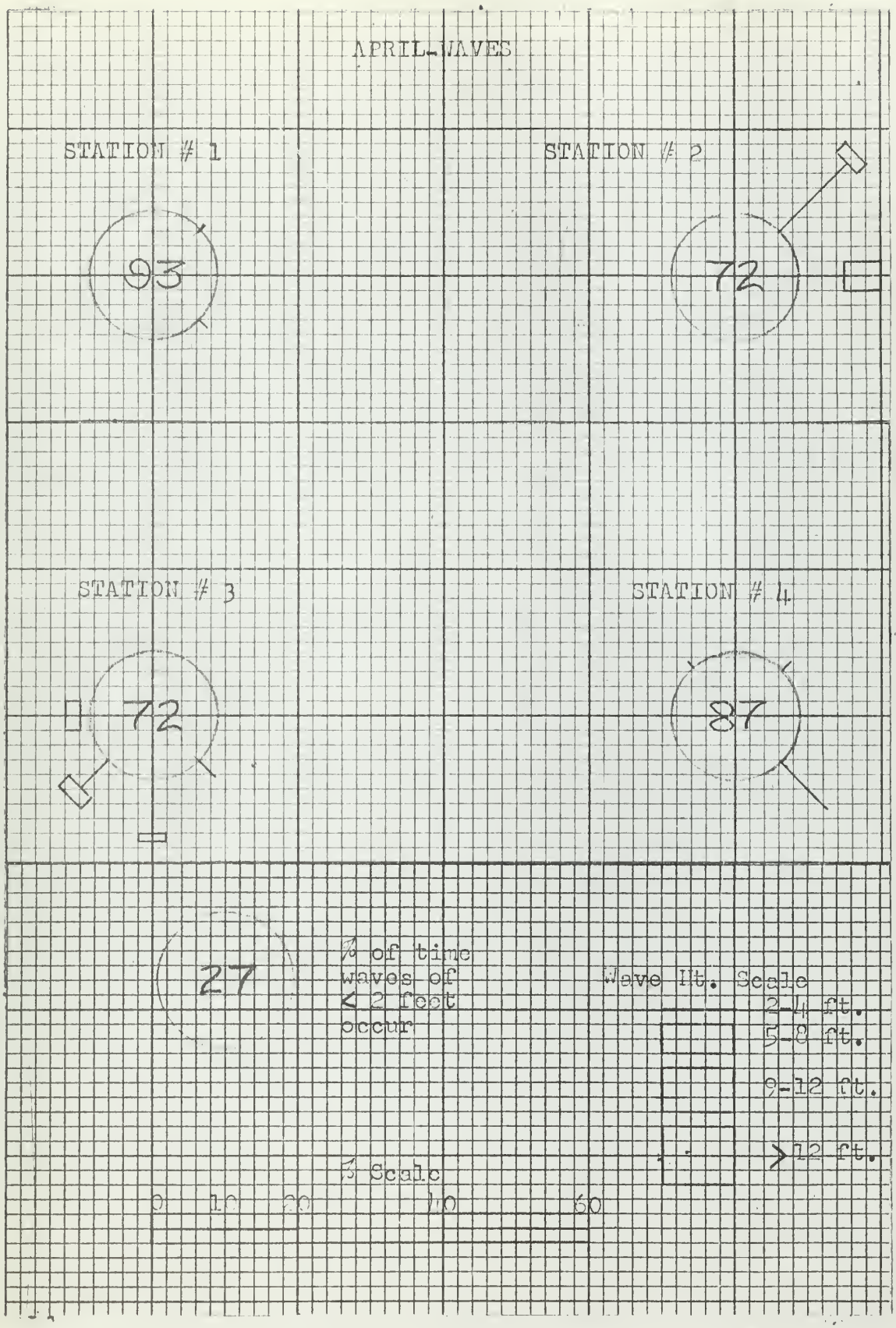
APPENDIX III

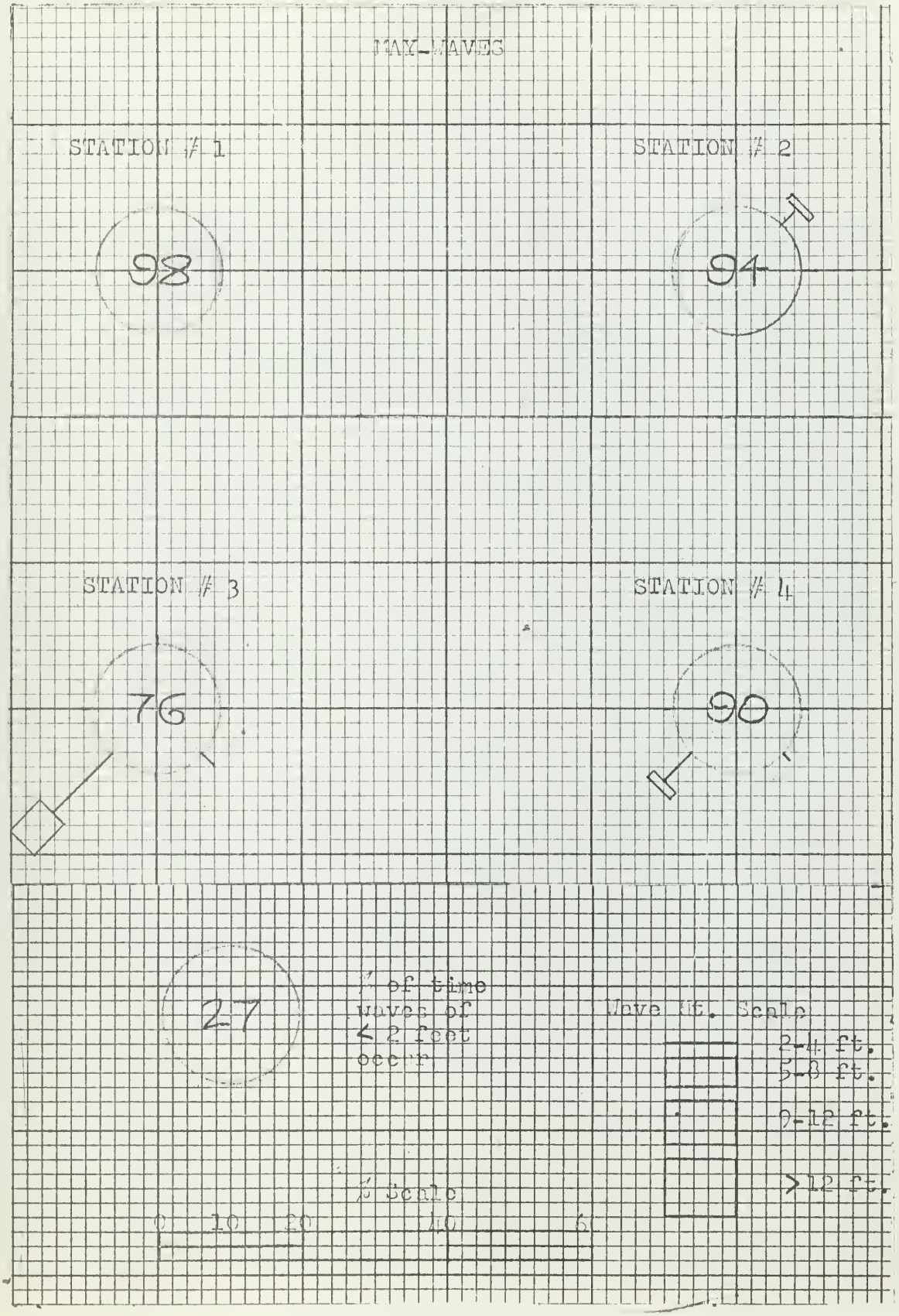
MONTHLY WAVE ROSES FOR FOUR STATIONS

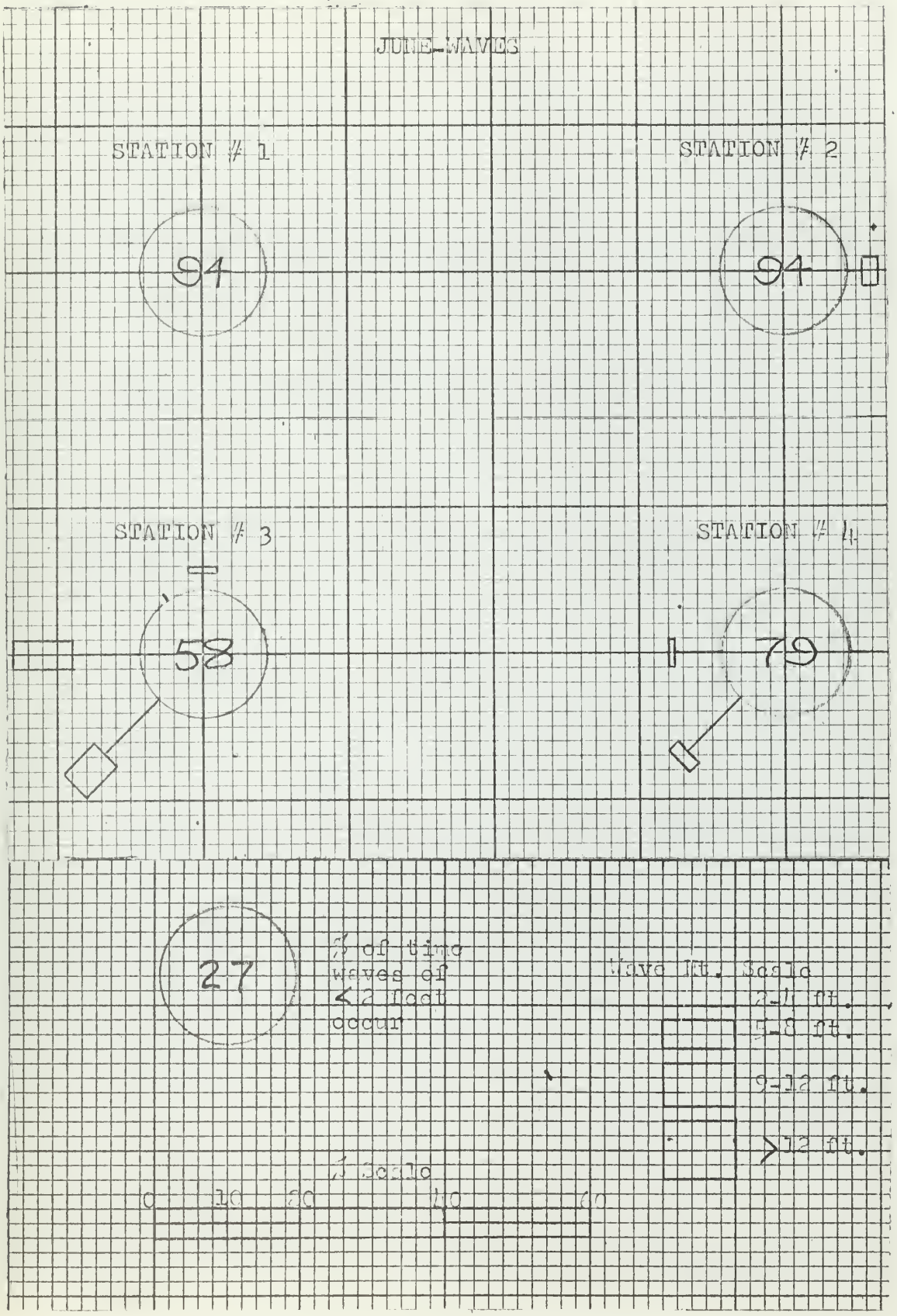

JANUARY-WAVES
STATION # 1
86
STATION # 2
19
STATION # 3
40
STATION # 4
36
27
% of time waves of < 2 feet occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
> 12 ft.
% Scale
0
10
20
40
60

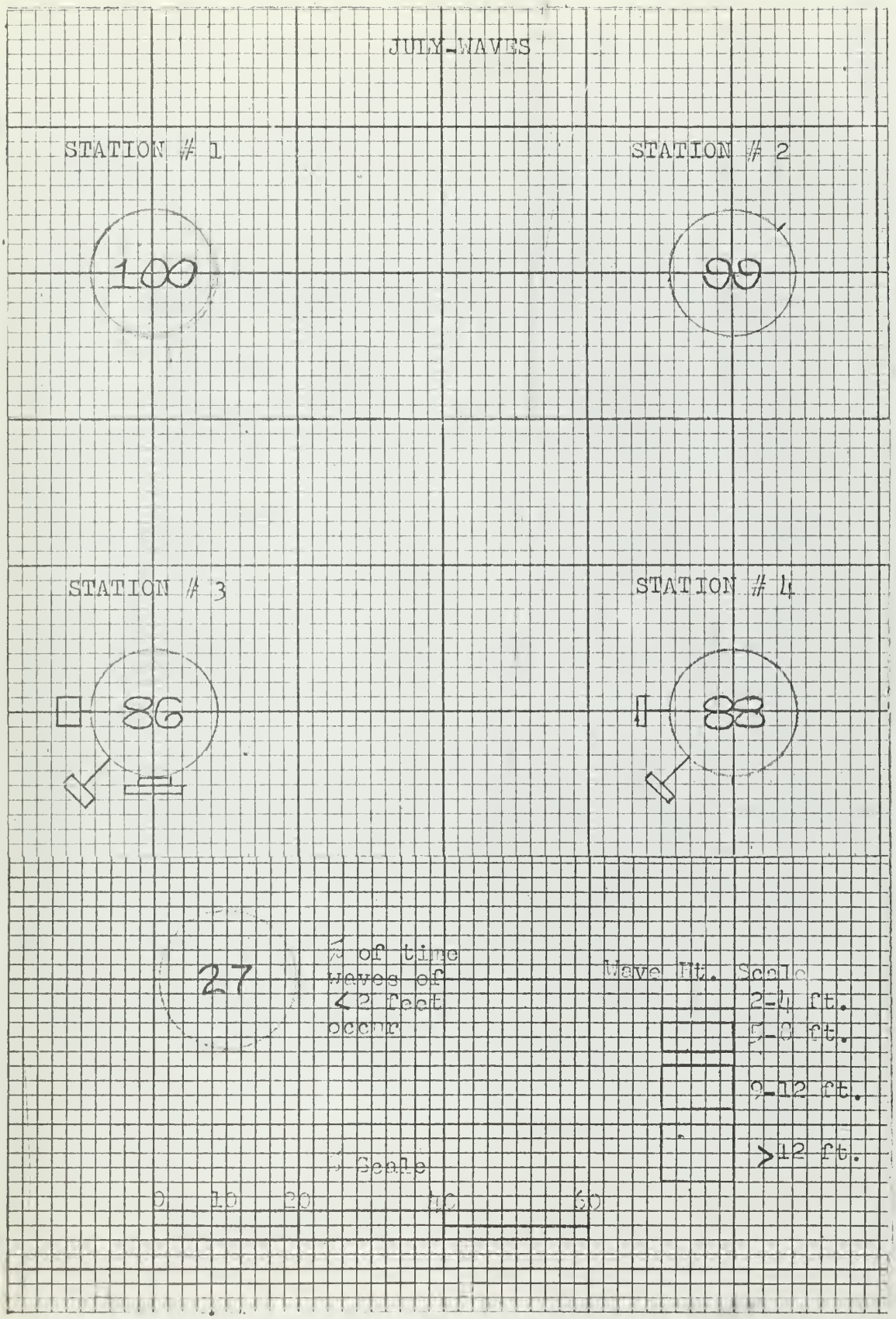

FEBRUARY-WAVES
STATION # 1
87
STATION # 2
14
STATION # 3
54
STATION # 4
39
27
% of time
waves of
< 2 feet
occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
>12 ft.
Scale
0
10
20
40
60

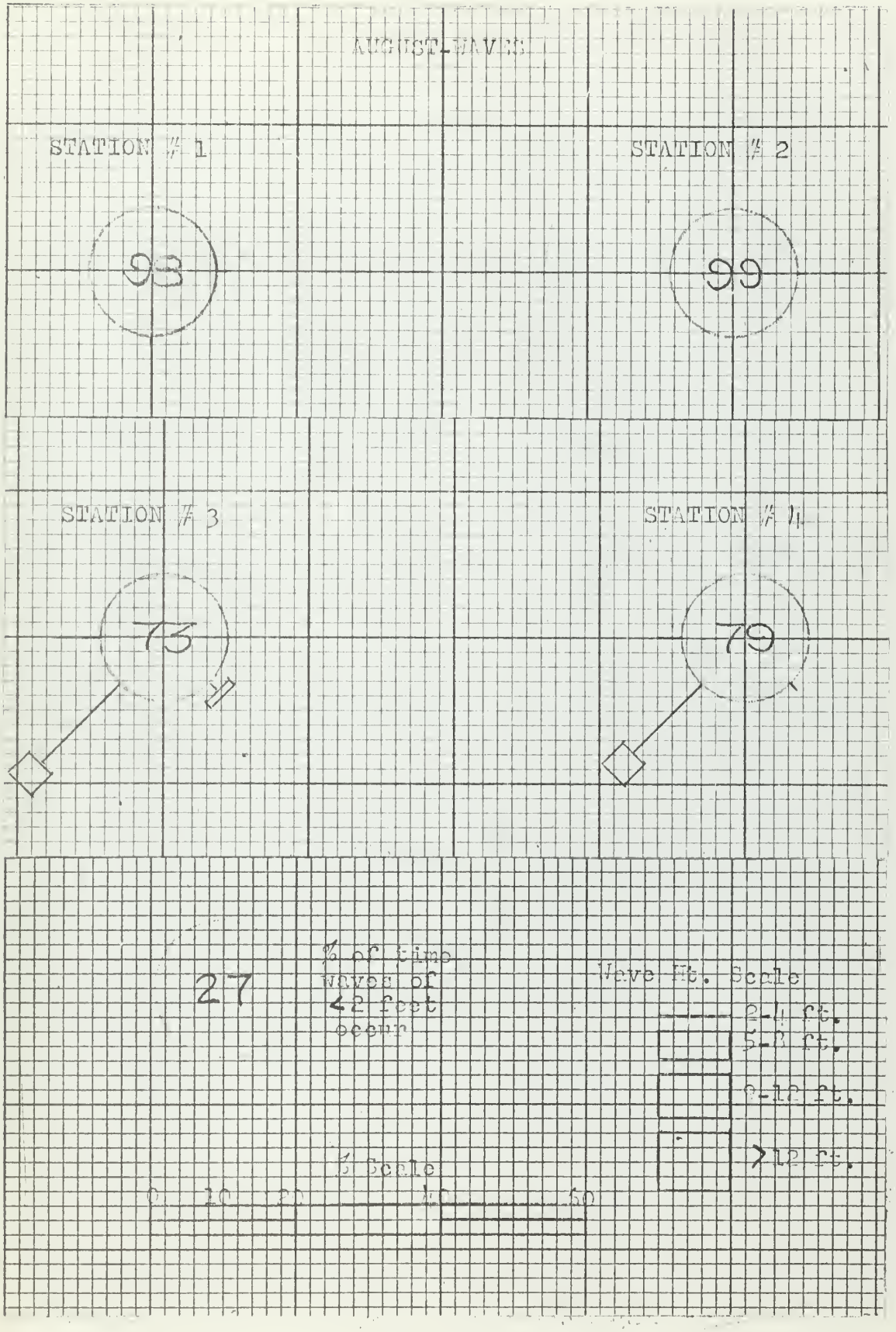

MARCH-WAVES
STATION # 1
91
STATION # 2
29
STATION # 3
52
STATION # 4
57
27
% of time
waves of
< 2 foot
occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
>12 ft.
% Scale
0
10
20
40
60

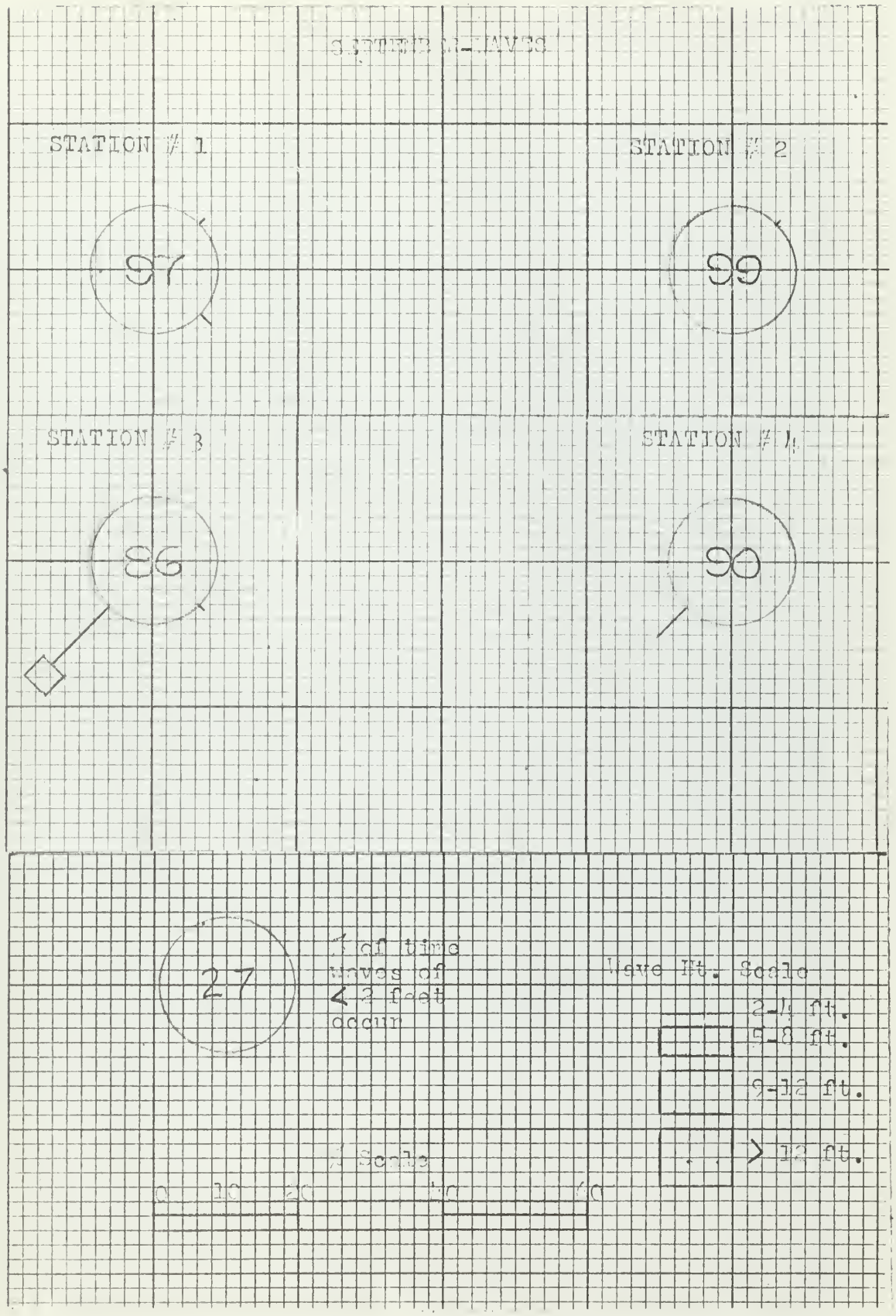

APRIL WAVES
STATION # 1
93
STATION # 2
72
STATION # 3
72
STATION # 4
87
27
% of time
waves of
< 2 feet
occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
>12 ft.
% Scale
0
10
20
40
60

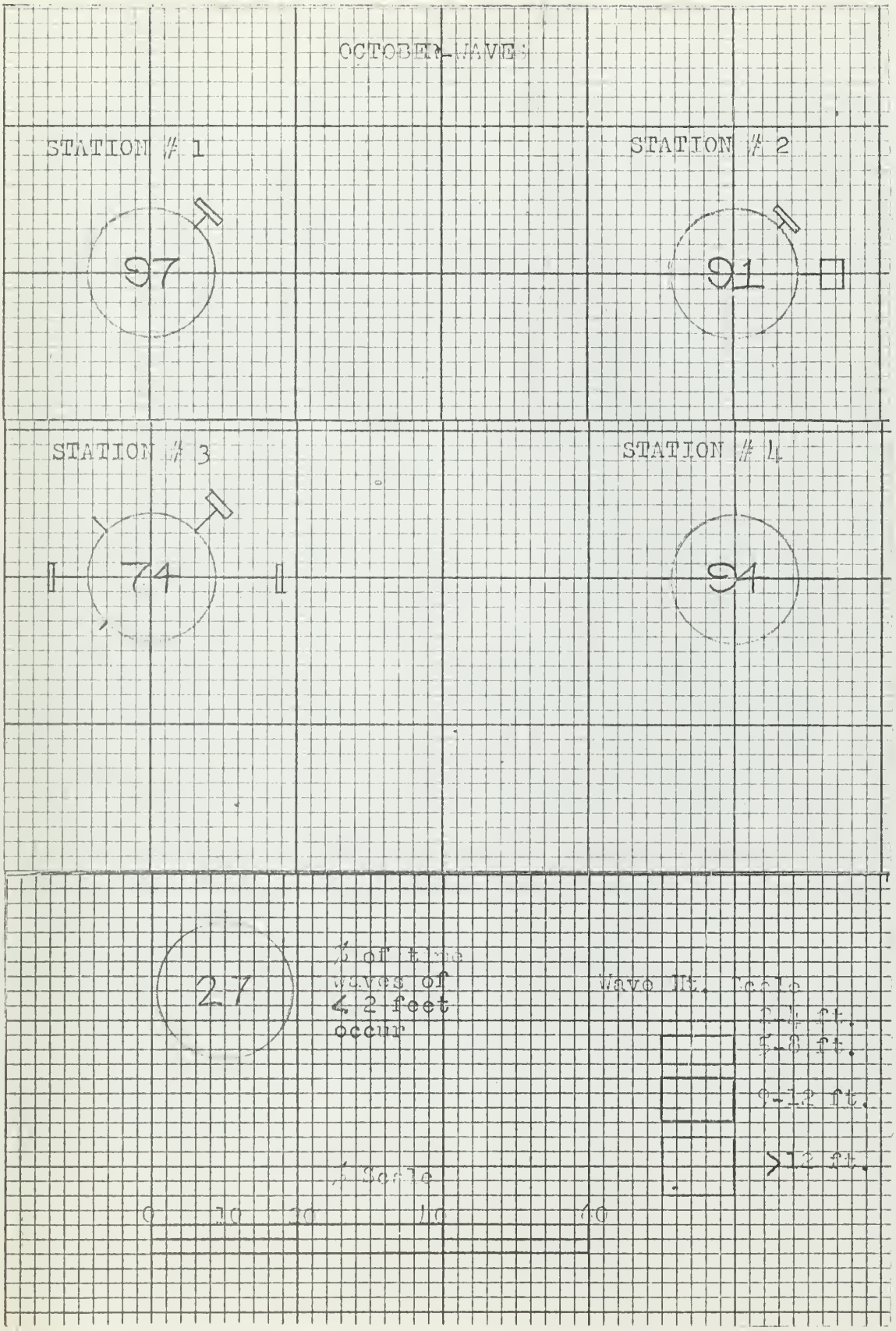

MAY-WAVES
STATION # 1
98
STATION # 2
94
STATION # 3
76
STATION # 4
90
27
% of time
waves of
< 2 feet
occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
> 12 ft.
% Scale
0
10
20
40
60

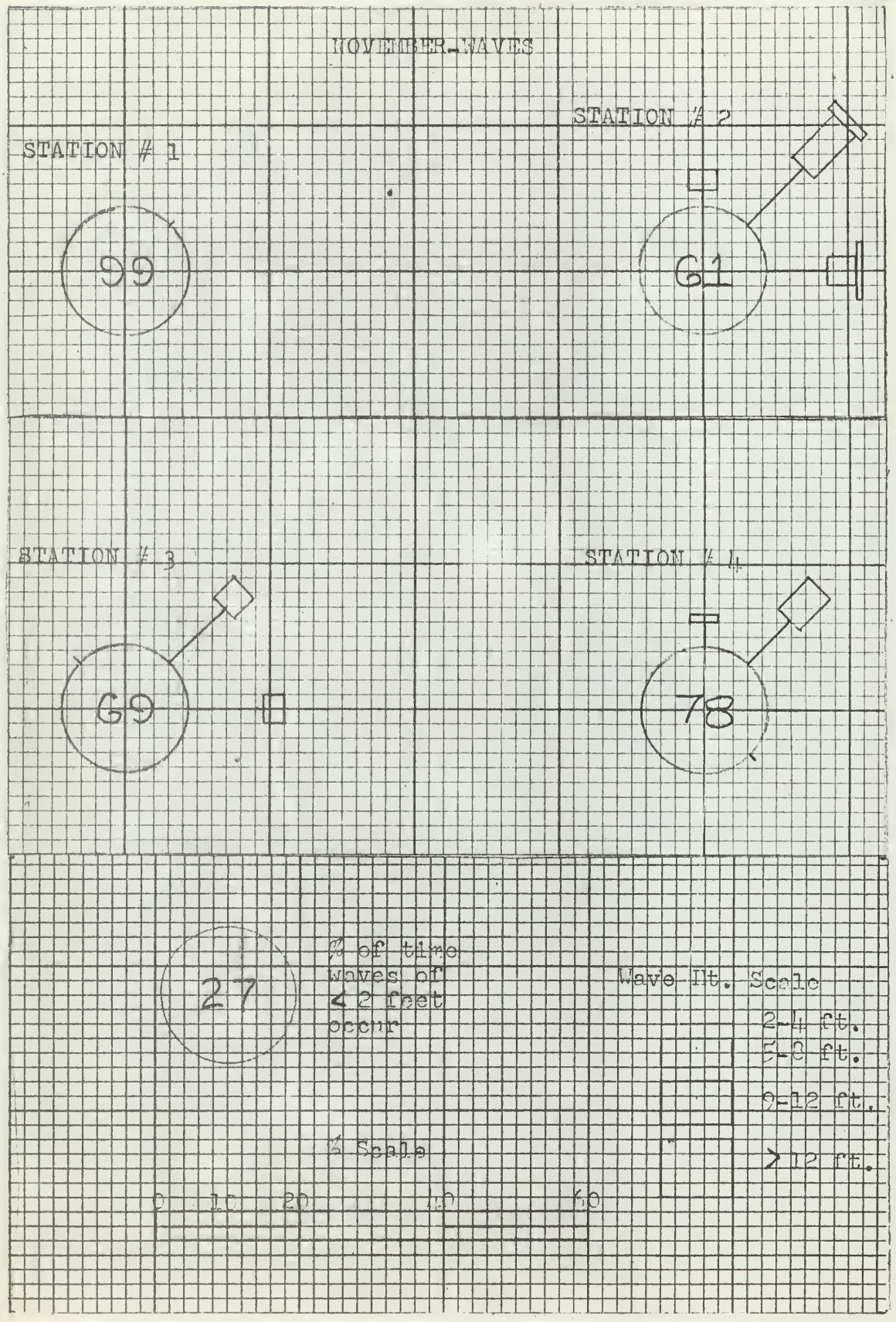

JUNE-WAVES
STATION # 1
94
STATION # 2
94
STATION # 3
58
STATION # 4
79
27
% of time
waves of
<2 feet
occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
>12 ft.
% Scale
0
10
20
30
40

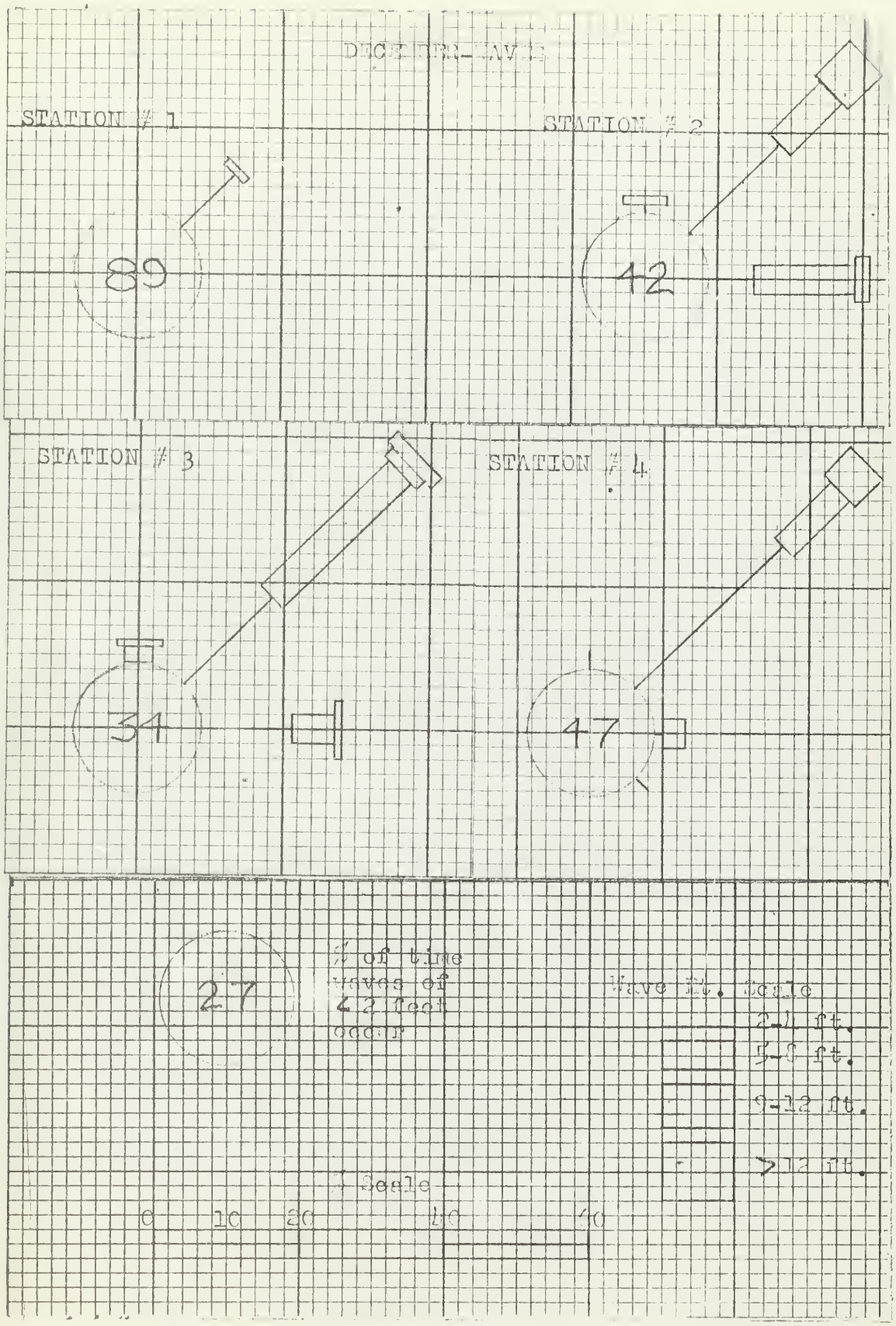

JULY-WAVES
STATION # 1
100
STATION # 2
99
STATION # 3
86
STATION # 4
88
27
% of time waves of < 2 feet occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
>12 ft.
% Scale
0
10
20
40
60


AUGUST-WAVES
STATION # 1
93
STATION # 2
99
STATION # 3
73
STATION # 4
79
27
% of time waves of <2 feet occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
>12 ft.
% Scale
0
10
20
40
50


STATION # 1
97
STATION # 2
99
STATION # 3
96
STATION # 4
90
27
% of time
waves of
< 2 feet
occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
> 12 ft.
% Scale
0
10
20
30
40


OCTOBER WAVES
STATION # 1
97
STATION # 2
91
STATION # 3
74
STATION # 4
94
27
% of time
waves of
< 2 feet
occur
Wave Ht. Scale
0-4 ft.
4-8 ft.
8-12 ft.
>12 ft.
% Scale
0
10
20
30
40


NOVEMBER-WAVES
STATION # 1
99
STATION # 2
61
STATION # 3
69
STATION # 4
78
27
% of time
waves of
< 2 feet
occur
% Scale
0
10
20
40
60
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
> 12 ft.


STATION # 1
89
STATION # 2
42
STATION # 3
34
STATION # 4
47
27
% of time
waves of
< 2 feet
occur
Wave Ht. Scale
2-4 ft.
5-8 ft.
9-12 ft.
>12 ft.
Scale
0
10
20
40

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